The Adventures of
ARCHIBALD HIGGINS

FLIGHT OF FANCY

Jean-Pierre Petit

Translated by Ian Stewart

The Association Knowledge without Borders, founded and chaired by Professor Jean-Pierre Petit, astrophysicist, aims at spreading scientific and technical knowledge in as many countries as possible and in as many languages as possible. To this end, all his popular scientific works, which cover a period of thirty years, and more particularly the illustrated albums he has created, are now freely accessible. Anyone is now free to duplicate the present file, either in digital form or in the form of printed copies and circulate these copies to libraries , within the context of schools or universities or associations whose aims would be the same as the association , provided that they do not derive any profit from this circulation and that they do not have any political, sectarian or confessional connotations. These pdf files may also be put on line in the computer networks of school and university libraries.

Jean-Pierre Petit intends to create numerous other works which will be accessible to a larger audience. Even illiterate people will be able to read them because the written parts will “speak” when the readers click on them. Thus it will be possible to use these works to support literacy schemes. Other albums will be "bilingual" in so far as it will be possible to switch from one language to another selected language with a mere click. Hence another tool made available to develop language skills.

Jean-Pierre Petit was born in 1937. He made his career in French research. He worked as a plasma physicist, he directed a computer science centre, he has created softwares, he has published hundreds of articles in scientific magazines, dealing with subjects ranging from fluid mechanics to theoretical cosmology. He has published about thirty books which have been translated in numerous languages.

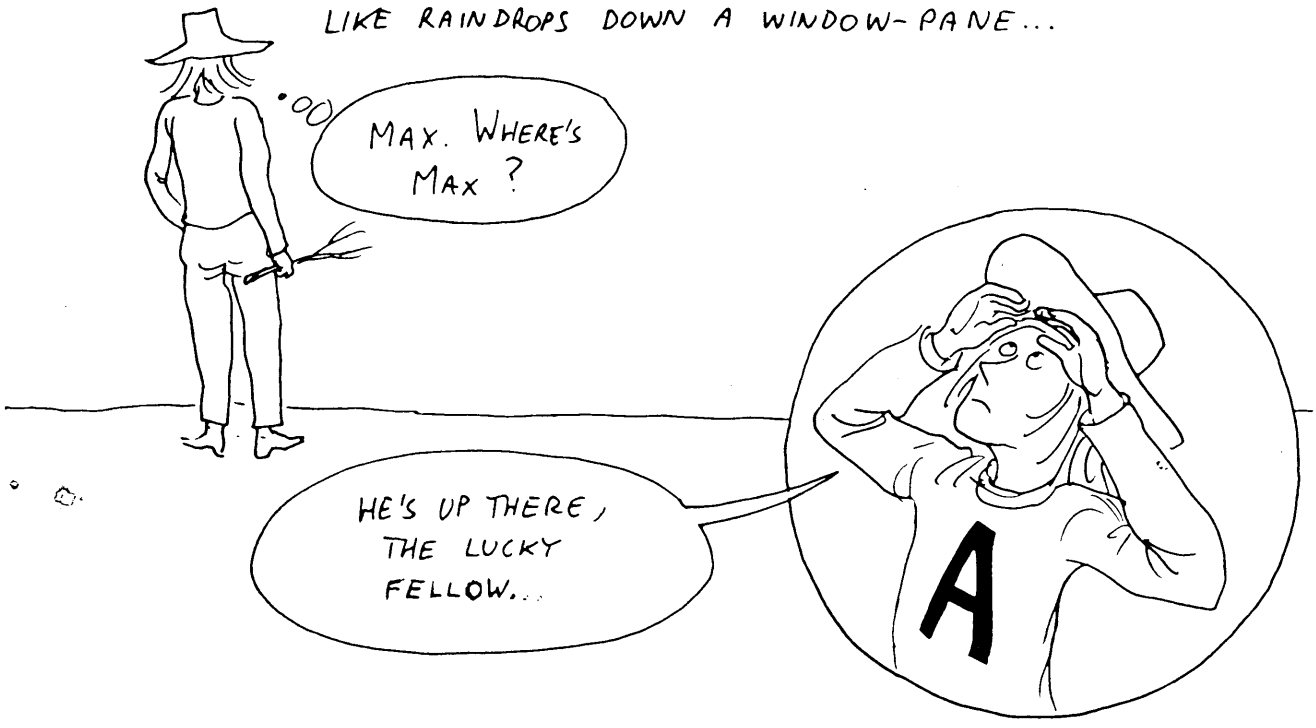
The association can be contacted on the following internet site:

http://savoir-sans-frontieres.com

PROLOGUE:

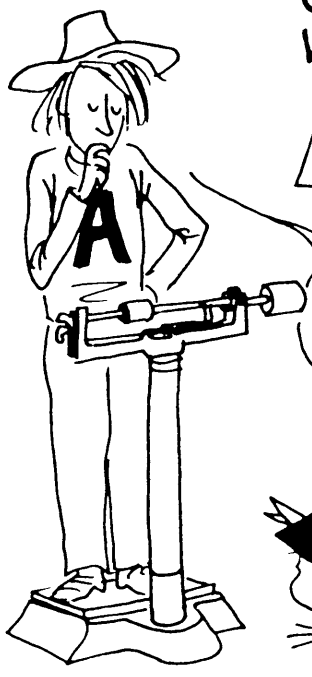

ONE MORNING, ARCHIBALD HIGGINS WOKE UP IN A ROTTEN MOOD...
YUK!
SUNDAY, MONDAY, TUESDAY, WEDNESDAY, THURSDAY...
FEB 16
... FRIDAY, SATURDAY, SUNDAY. AND THEN IT STARTS ALL OVER AGAIN. BORING, ISN'T IT?
I'M NOT SURPRISED. THE BUTTERED SIDE, NO DOUBT.

ARCHIE FELT SAD AND EMPTY. EVEN THE EARTH WAS FLAT. THE DAYS TRICKLED PAST LIKE RAINDROPS DOWN A WINDOW-PANE...




YOU? FLY? GOOD HEAVENS!
MAX - YOU'VE GOT TO TEACH ME TO FLY. JUST A LITTLE BIT. IT'S GETTING ME DOWN, STUCK ON THE GROUND LIKE THIS.
LOOK - I CAN LIFT ONE FOOT. IF I LIFT THE OTHER ONE QUICKLY ENOUGH, MAYBE I CAN...
IT MUST HAVE BEEN THE WEIGHT OF ALL THAT AIR, PUSHING ME BACK DOWN AGAIN.
QUITE THE CONTRARY, OLD BOY! ACCORDING TO ARCHIMEDES' PRINCIPLE, THE AIR PRESSURE ACTUALLY REDUCES YOUR WEIGHT BY 80 GRAMS.

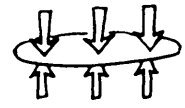
ONCE UPON A TIME THERE WAS A MAN CALLED ARCHIMEDES



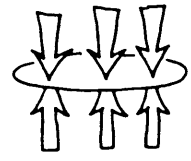
YOU MEAN TO TELL ME THAT WHEN I WEIGH MYSELF, THE MACHINE DOESN'T GIVE MY TRUE WEIGHT – BECAUSE OF **AIR PRESSURE** ?

PRECISELY. YOU ACTUALLY WEIGH 80 GRAMS MORE.

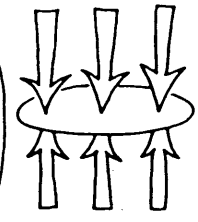
HMM... ARCHIMEDES' PRINCIPLE. I'VE HEARD THE **WORDS** OFTEN ENOUGH- BUT WHAT **IS** IT REALLY ?

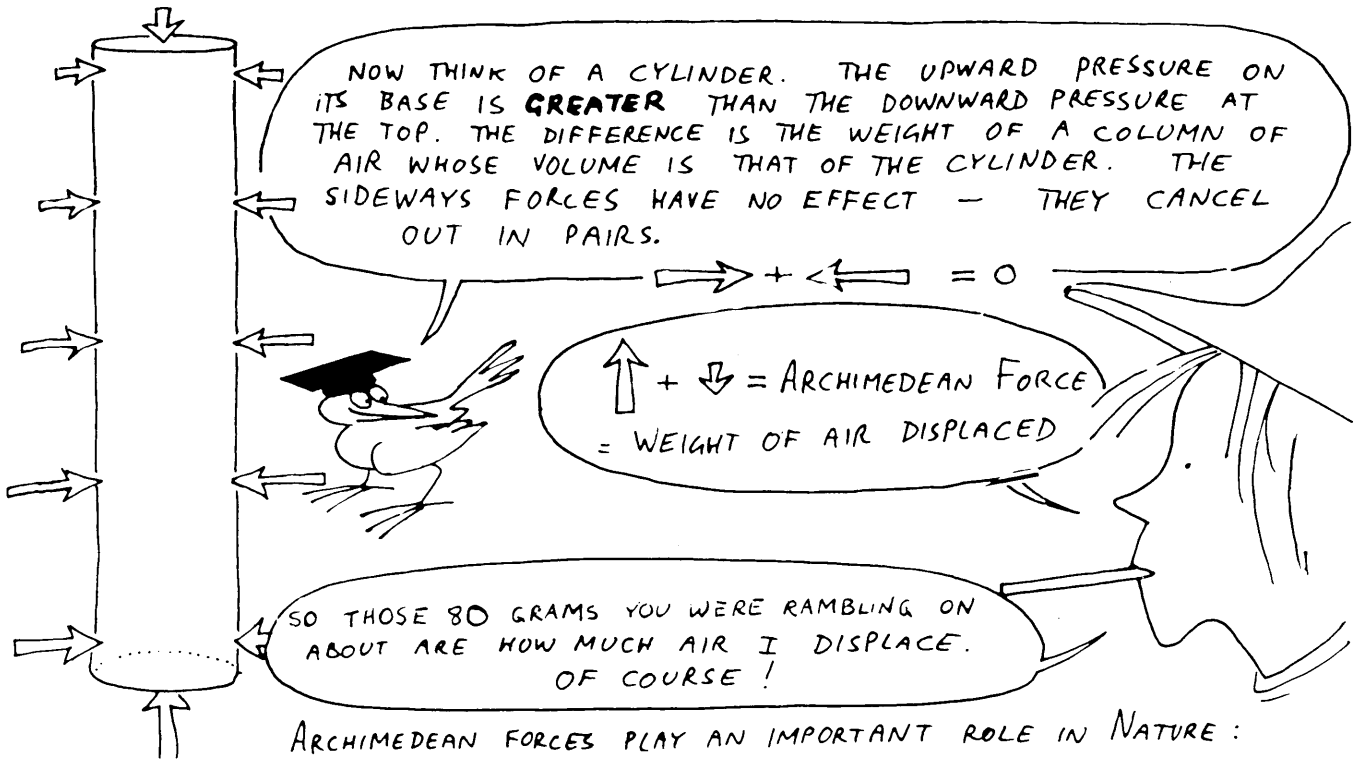


FORCES ACTING ON A DISC IMMERSED IN A FLUID:



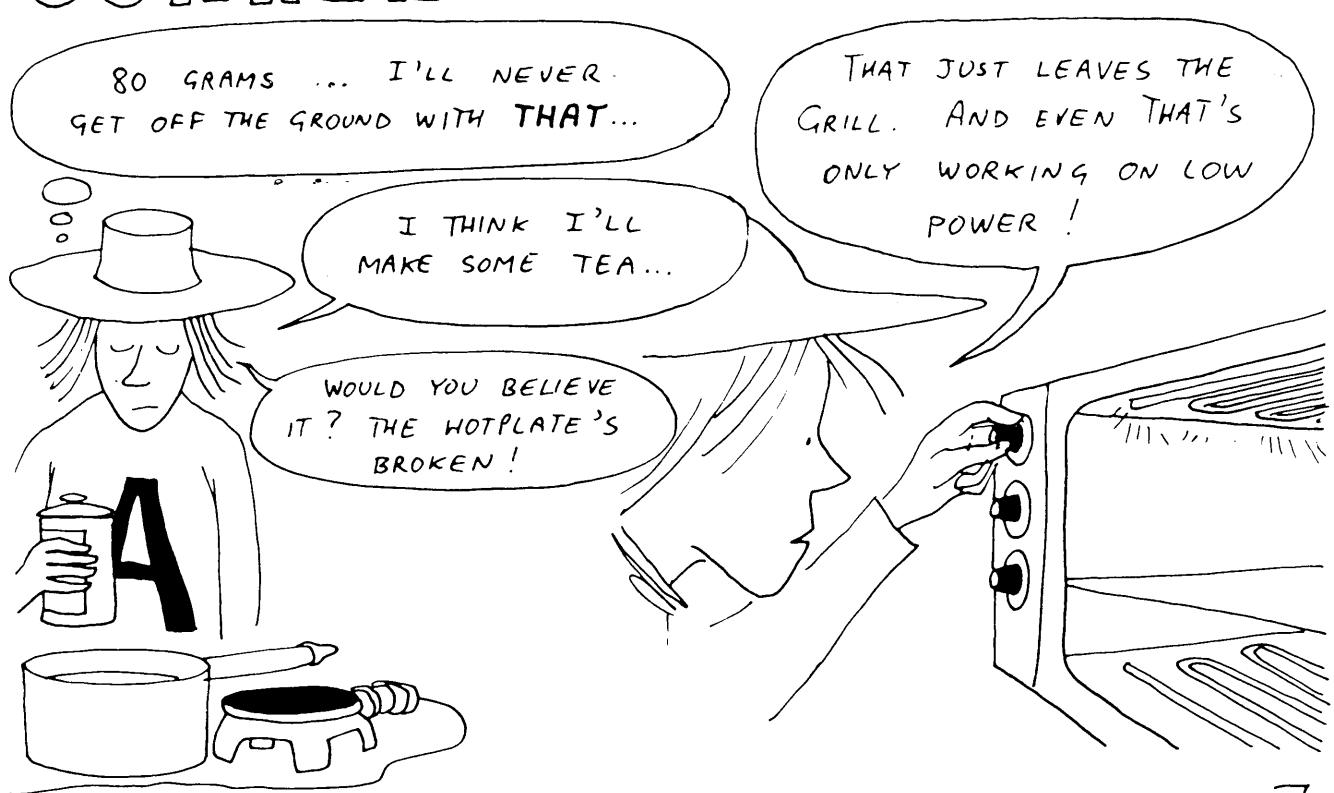
THINK OF A DISC SITTING IN THE ATMOSPHERE. THE ENTIRE COLUMN OF AIR OVER THE TOP PUSHES IT DOWNWARDS. BUT AN EQUAL AND OPPOSITE FORCE ACTS FROM UNDERNEATH – SO THE TWO PRESSURE FORCES CANCEL OUT. THE "DEEPER" THE DISC IS IN THE ATMOSPHERE, THE GREATER THESE FORCES BECOME...

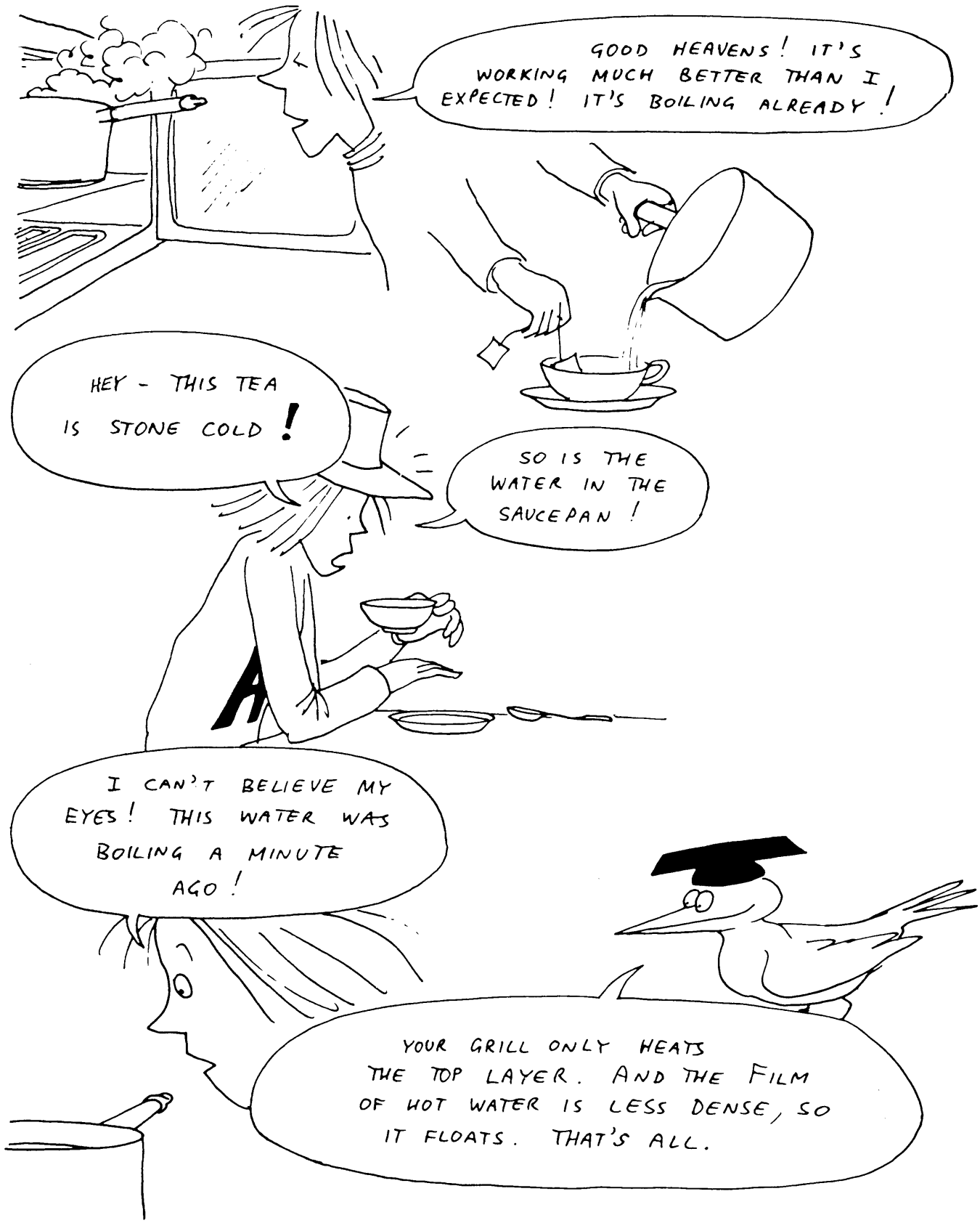


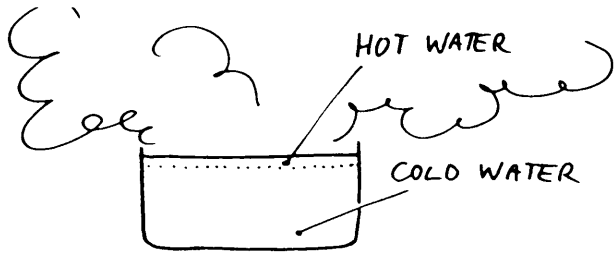


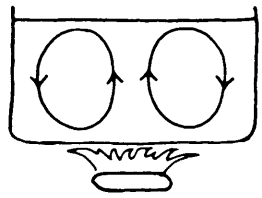
ARCHIMEDEAN FORCES PLAY AN IMPORTANT ROLE IN NATURE :

CONVECTION CURRENTS

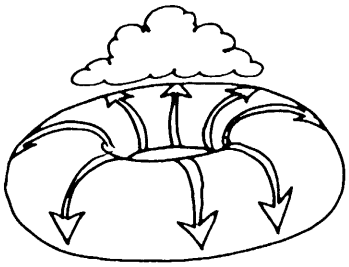



GOOD HEAVENS! IT'S WORKING MUCH BETTER THAN I EXPECTED! IT'S BOILING ALREADY!
HEY - THIS TEA IS STONE COLD!
SO IS THE WATER IN THE SAUCEPAN!
I CAN'T BELIEVE MY EYES! THIS WATER WAS BOILING A MINUTE AGO!
YOUR GRILL ONLY HEATS THE TOP LAYER. AND THE FILM OF HOT WATER IS LESS DENSE, SO IT FLOATS. THAT'S ALL.

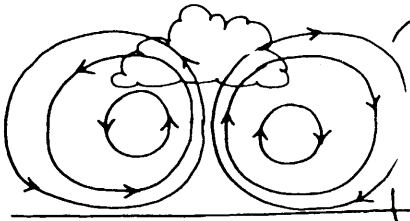




ON THE OTHER HAND, IF YOU HEAT THE WATER FROM BELOW IT GETS **LESS** DENSE, AND RISES IN A COLUMN. WHEN IT REACHES THE TOP IT COOLS, CONTRACTS, AND DESCENDS AGAIN ON THE OUTSIDE. THIS IS **NATURAL CONVECTION**.

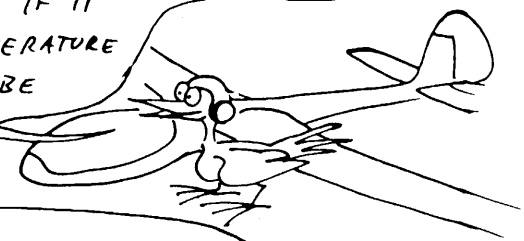


THE SAME THING OCCURS IN THE ATMOSPHERE. WARM AIR, LADEN WITH MOISTURE, RISES FROM A HOT SPOT. WHEN IT COOLS, THE VAPOR CONDENSES, FORMING A NICE **CUMULUS CLOUD**.



HOT SPOT

THIS MIXES THE AIR AND MAKES THE TEMPERATURE MORE EVENLY DISTRIBUTED. IF IT DIDN'T HAPPEN, THE TEMPERATURE ON A SUNNY DAY WOULD BE HUNDREDS OF DEGREES.

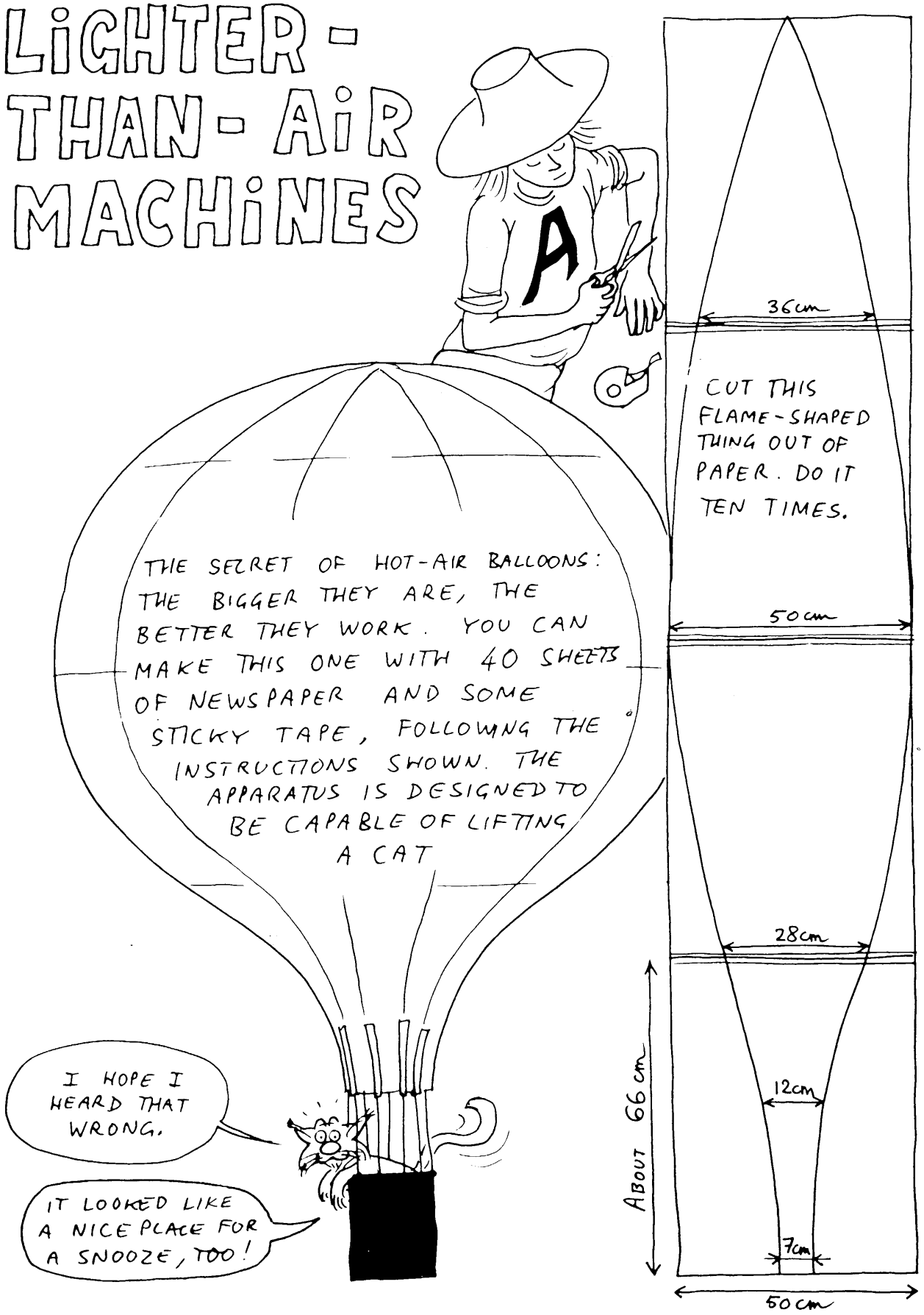


IF I HITCHED MYSELF TO ONE OF THOSE LUMPS OF WARM AIR, MAYBE I'D BE ABLE TO FLY?

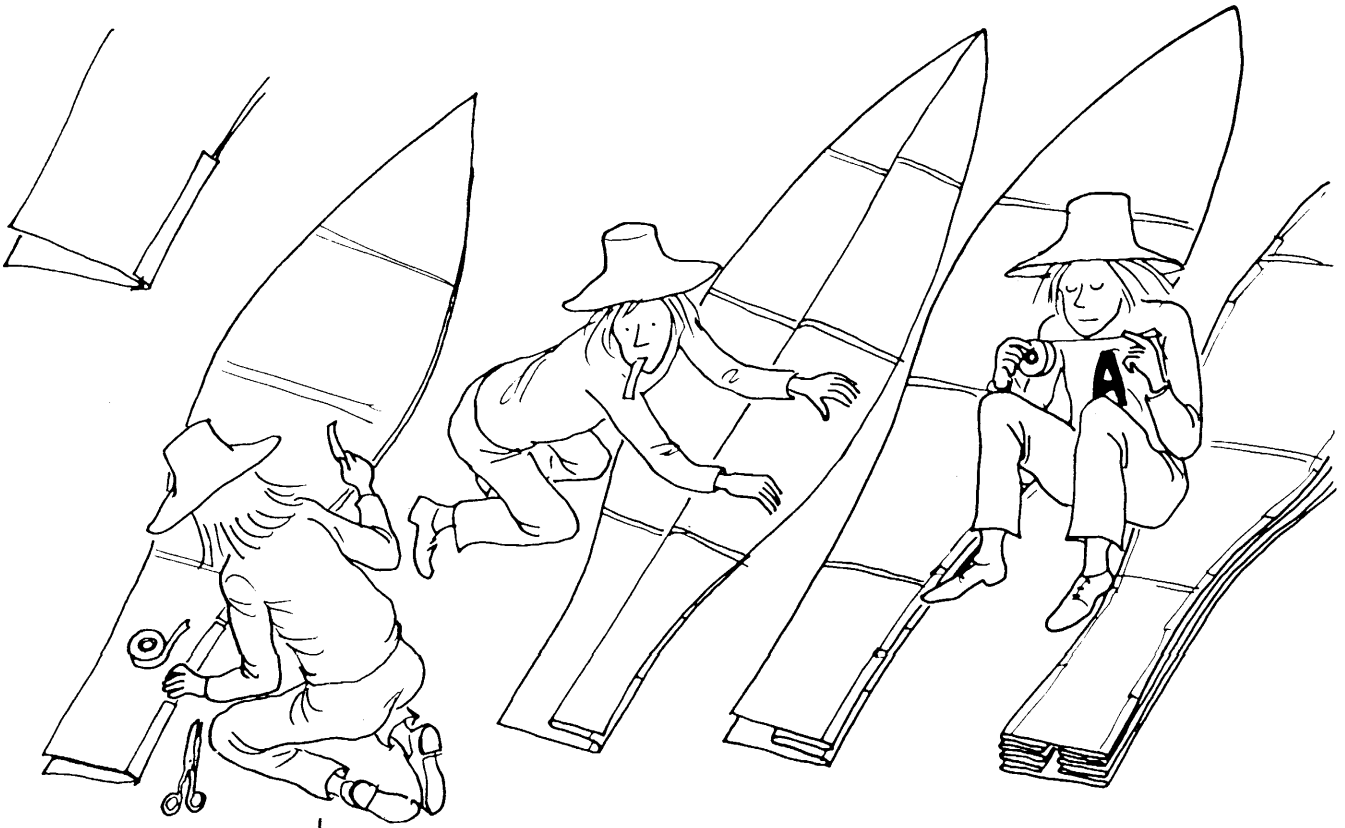
WATCH WHAT YOU'RE DOING WITH THOSE HUGE FEET, YOU KLUTZ!

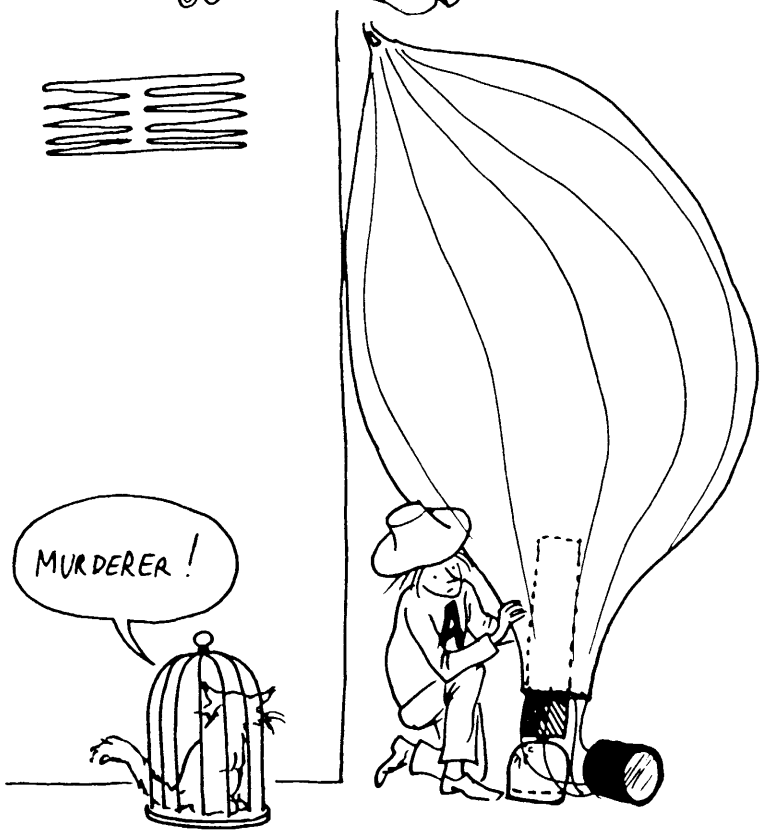

WHO SAID THAT ?
WHY DON'T YOU DO YOUR THINKING SOMEWHERE ELSE, FATHEAD ?
YOU'VE JUST STOMPED ALL OVER OUR ANTHILL !
OH, SORRY.
FLYING ? AS IF LIFE WASN'T COMPLICATED ENOUGH ALREADY !
ANYWAY, OUR SCIENTISTS HAVE PROVED THAT IT'S A MATHEMATICAL IMPOSSIBILITY !
FRANKLY, PAL, DON'T YOU RECKON THERE ARE MORE IMPORTANT THINGS THAN FLYING ?
HANG ON - THAT'S ALL I EVER DO !
EUREKA ! I'LL PUT A LUMP OF WARM AIR IN SOME SORT OF WRAPPING ...

LIGHTER-THAN-AIR MACHINES



HERE'S HOW ARCHIE PUT HIS HOT-AIR BALLOON TOGETHER...





HEAT IT USING A CAMP-STOVE, PROTECTING THE PAPER WITH A LENGTH OF METAL PIPE.

DON'T PUT THE CAT IN UNTIL THE LAST POSSIBLE MOMENT...

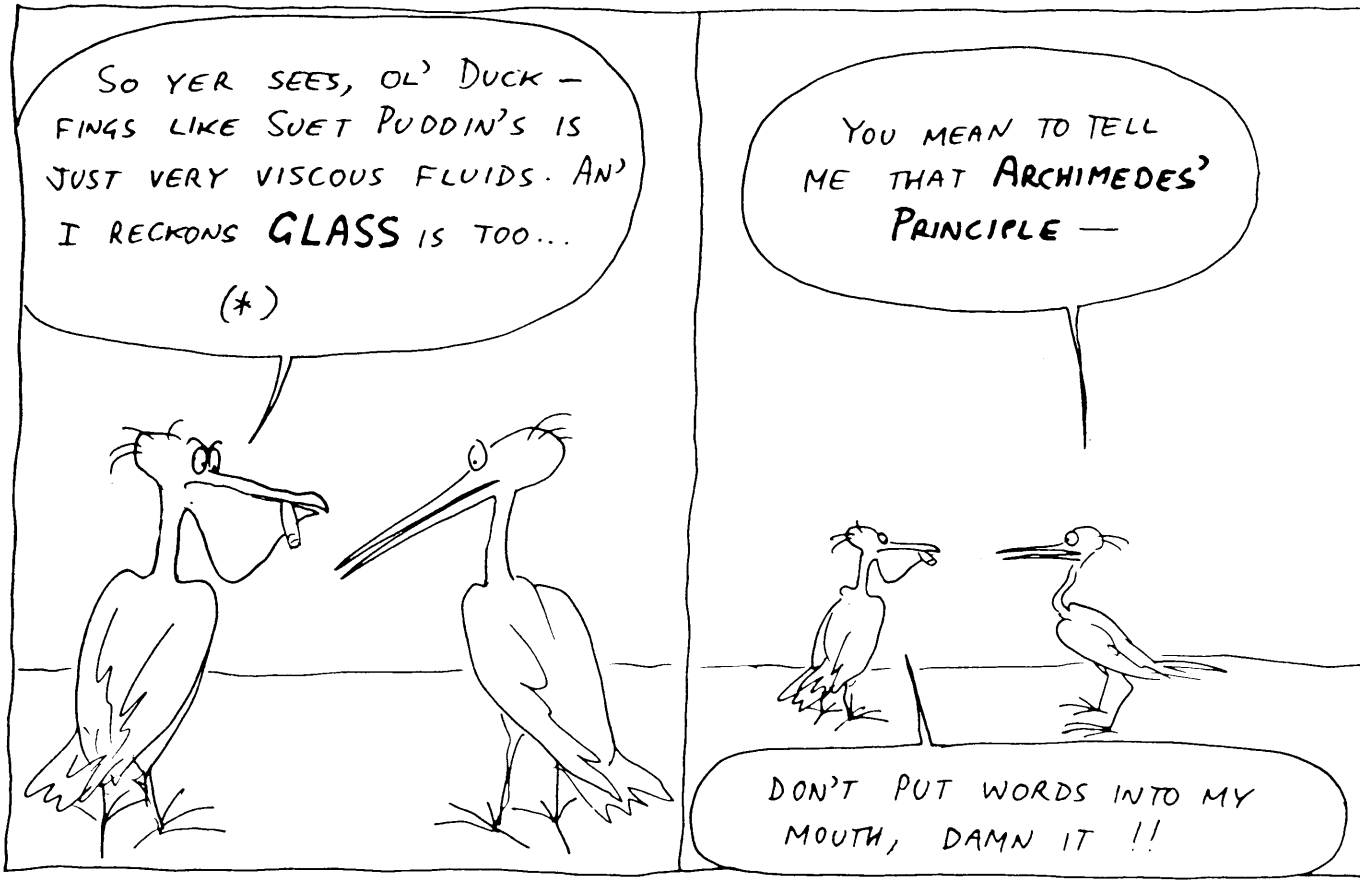

ITS FIVE-YEAR MISSION: TO BOLDLY GO WHERE NO CAT HAS EVER GONE BEFORE!
BEAM US DOWN, MR. SPOCK!
ALL RIGHT FOR PAPER TIGERS, I SUPPOSE... BUT ALL THE HOT AIR IN ALL THE NEWSPAPERS OF THE WORLD WON'T GIVE ME MUCH OF A LIFT...
WHAT IS THE SECRET OF FLIGHT, MAX?
BUZZ OFF, ARCHIE! I'M WORN OUT!


No good, blast it! THIS won't work. I must have missed something...
Oh dear.
Archie — to fly, you have to know something about FLUID MECHANICS. It's not as easy as you seem to imagine!
Fine — but what IS a Fluid? Is it just anything that FLOWS?
Yes, if you like. But even that is more complicated than you'd think.

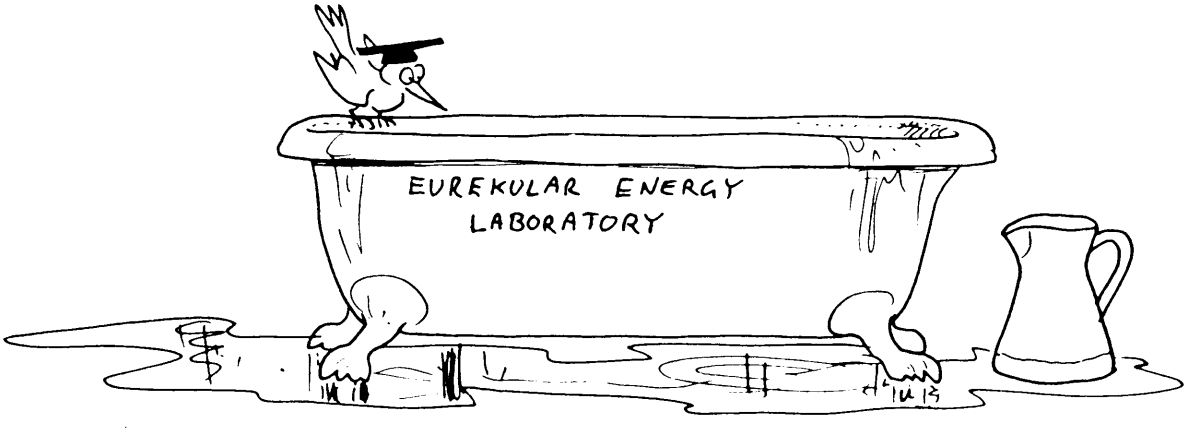
SAND FLOWS THE SAME AS WATER. I WONDER IF THERE'S SOME KIND OF CONNECTION?
O.K...
A
SOPHIE - DOES ARCHIMEDES' PRINCIPLE WORK FOR SAND?
IS SAND A FLUID?
FLUIDS
YOU'VE JUST GOT TO TRY IT!
RIGHT. SO HERE'S A COIN AND A TABLE-TENNIS BALL, AND A TROUGH FULL OF SAND. IF SAND IS A FLUID, THEN ARCHIMEDES' PRINCIPLE SAYS THAT THESE OBJECTS, BURIED IN SAND, SHOULD BE SUBJECT TO A FORCE, DIRECTED UPWARDS, AND EQUAL TO THE WEIGHT OF SAND DISPLACED.
OH - OH!

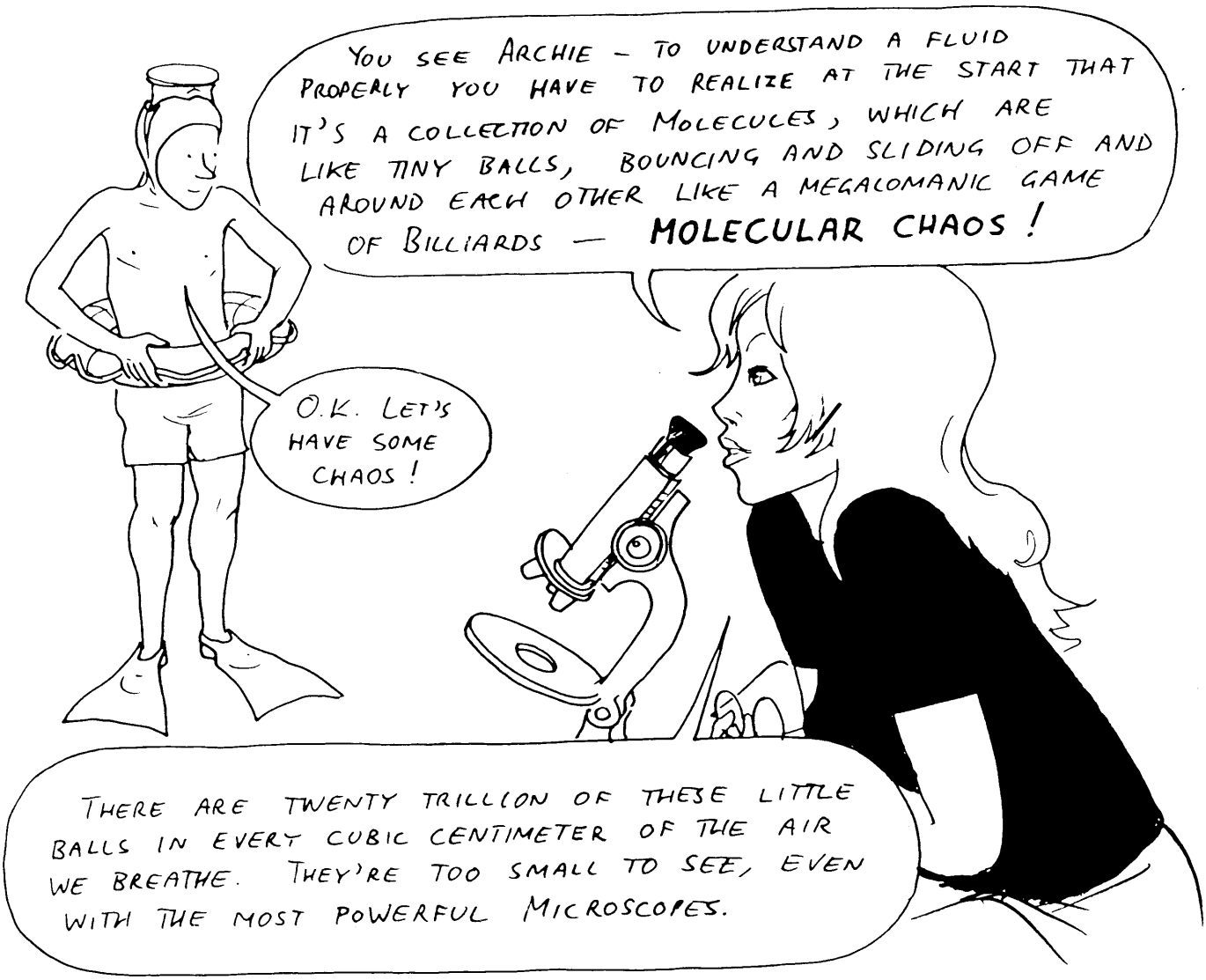
*SHAKESPEARE: MACBETH V iii 47


BLIMEY! THE BALL'S FLOATED TO THE TOP!
AND THE COIN HAS SUNK TO THE BOTTOM. WHEN WE SHOOK THE SAND, ARCHIE LET THE GRAINS SLIDE PAST EACH OTHER AND THE SAND BECAME FLUID.
SOPHIE SAYS THAT THE FINER THE GRAINS ARE, THE LESS TIME IT WILL TAKE.
OH. SO A FLUID IS A KIND OF SAND WITH VERY FINE GRAINS, WHICH CAN EASILY SLIDE PAST EACH OTHER?
THERE'S MORE THAN A GRAIN OF TRUTH IN THAT. SOPHIE SAYS IT'S HOW LUCRETIUS, IN THE 1ST CENTURY A.D., GOT THE IDEA OF ATOMS. (De Natura Rerum).
SOPHIE ALWAYS KNOWS BETTER THAN ANYONE ELSE!
A

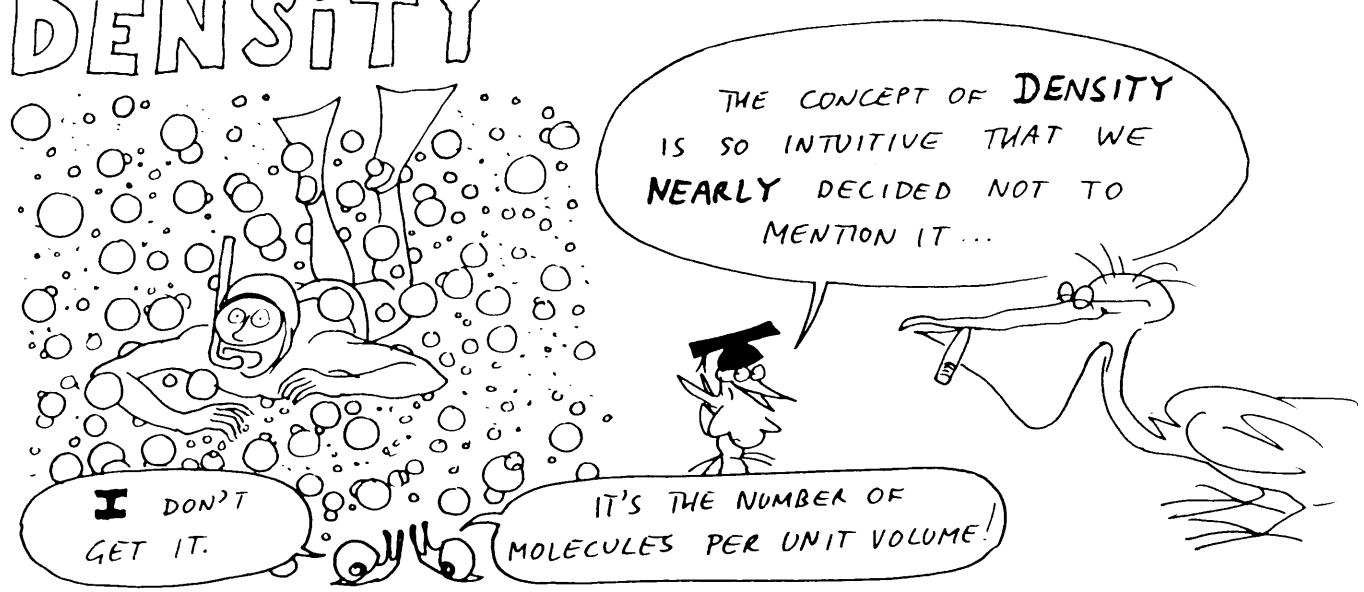


(*) GLASS IS EFFECTIVELY A VERY VISCOUS **LIQUID.**



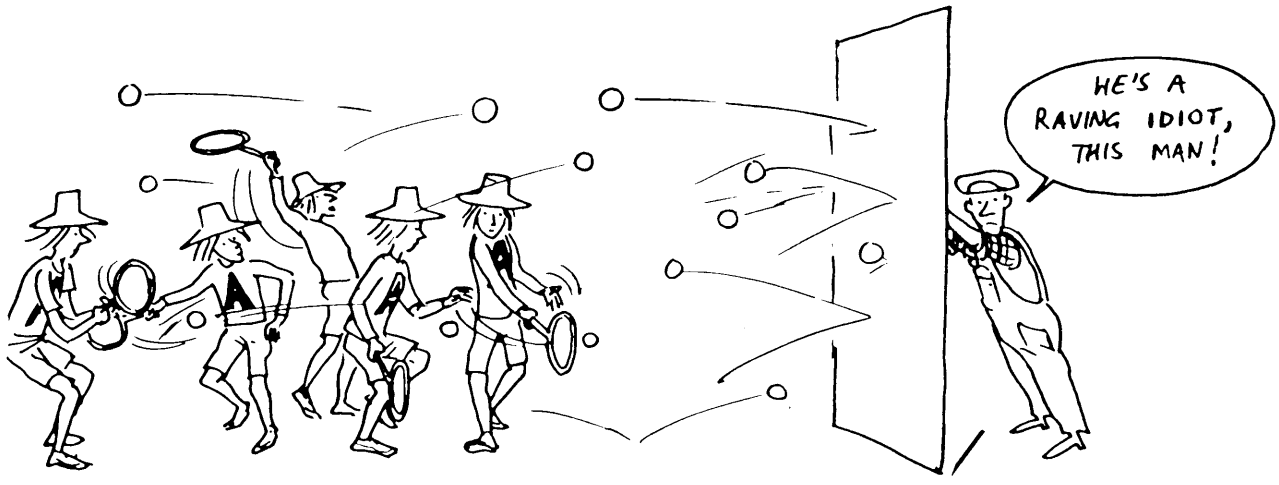

YOU SEE ARCHIE – TO UNDERSTAND A FLUID PROPERLY YOU HAVE TO REALIZE AT THE START THAT IT'S A COLLECTION OF MOLECULES, WHICH ARE LIKE TINY BALLS, BOUNCING AND SLIDING OFF AND AROUND EACH OTHER LIKE A MEGALOMANIC GAME OF BILLIARDS – MOLECULAR CHAOS!
O.K. LET'S HAVE SOME CHAOS!
THERE ARE TWENTY TRILLION OF THESE LITTLE BALLS IN EVERY CUBIC CENTIMETER OF THE AIR WE BREATHE. THEY'RE TOO SMALL TO SEE, EVEN WITH THE MOST POWERFUL MICROSCOPES.

DENSITY

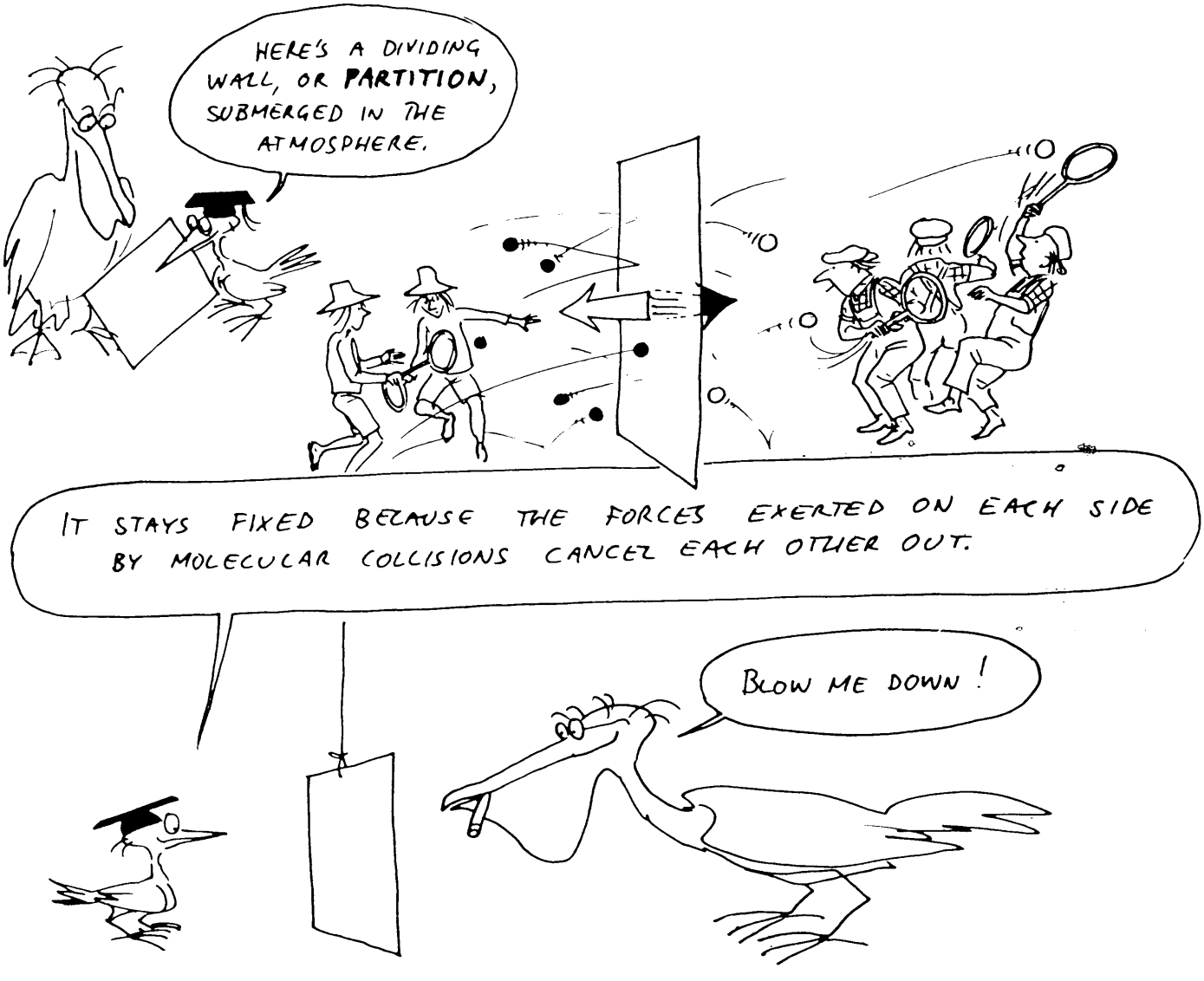

THE CONCEPT OF DENSITY IS SO INTUITIVE THAT WE NEARLY DECIDED NOT TO MENTION IT...
I DON'T GET IT.
IT'S THE NUMBER OF MOLECULES PER UNIT VOLUME!

PRESSURE:

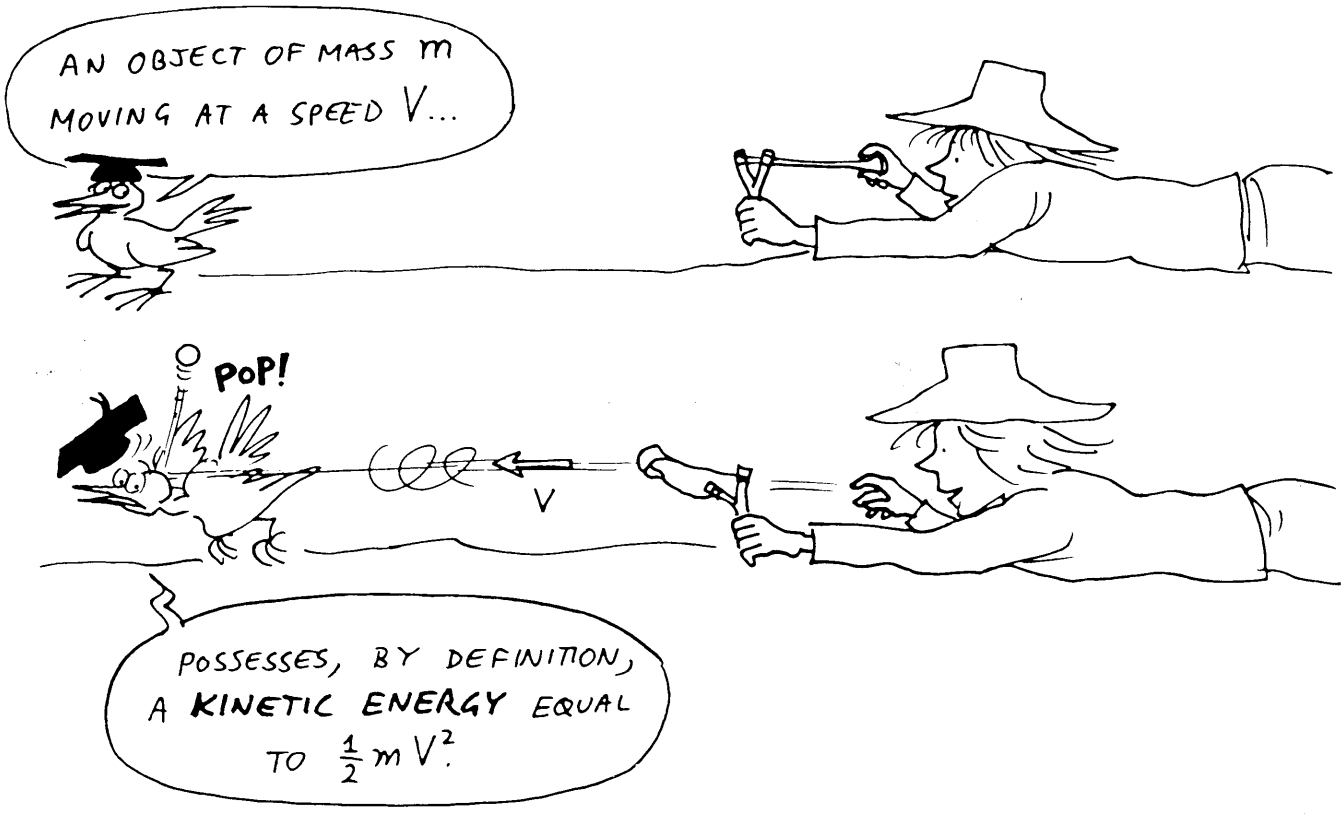

HMMM... THIS LOOKS LIKE A GOOD PLACE TO PRACTICE...
A
I'VE JUST GOT THIS BOARD NICELY BALANCED. I'LL JUST RELAX FOR A WHILE, AND THEN I'LL COME BACK AND FIX IT PROPERLY.
BOING
Oooooooops!!
FALLING IN LOVE AGAIN, NEVER WANTED TO, WHAT AM I TO DO, CAN'T ...
SO WOT'S ALL THAT S'POSED TER TELL US THEN, MATE?
YOU'LL SEE, YOU'LL SEE!



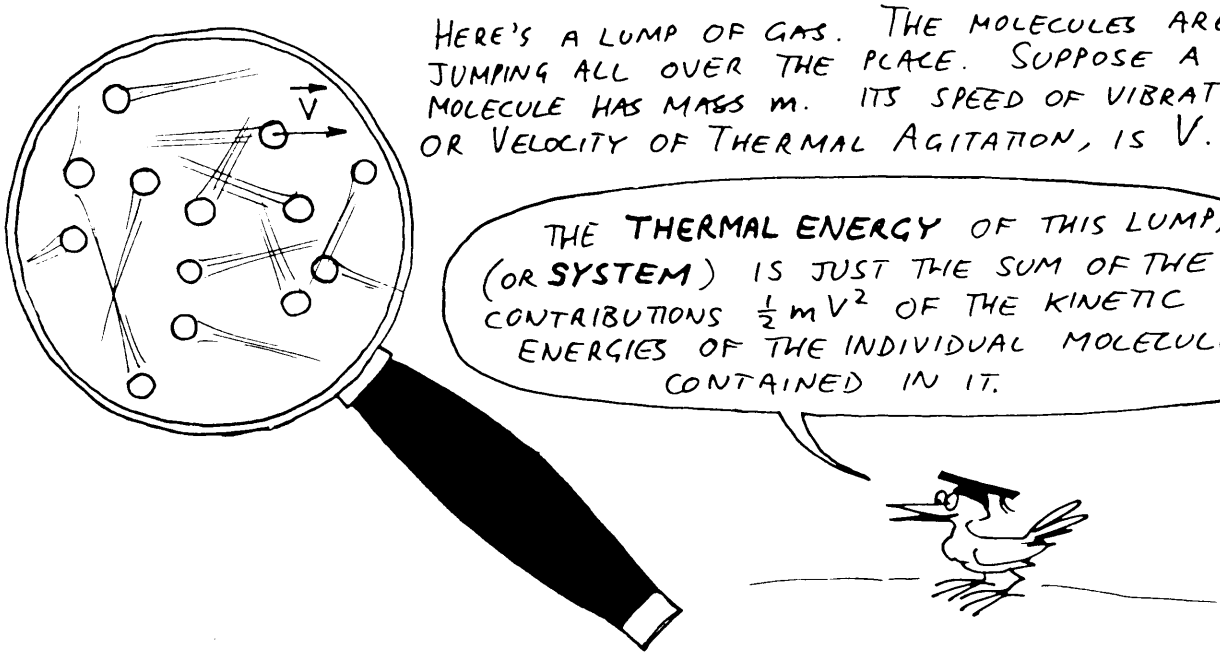
IT IS THESE INNUMERABLE MOLECULAR SHOCKS THAT HAPPEN AT A WALL, THAT PRODUCE THE EFFECT WE CALL **PRESSURE.**



KINETIC ENERGY:



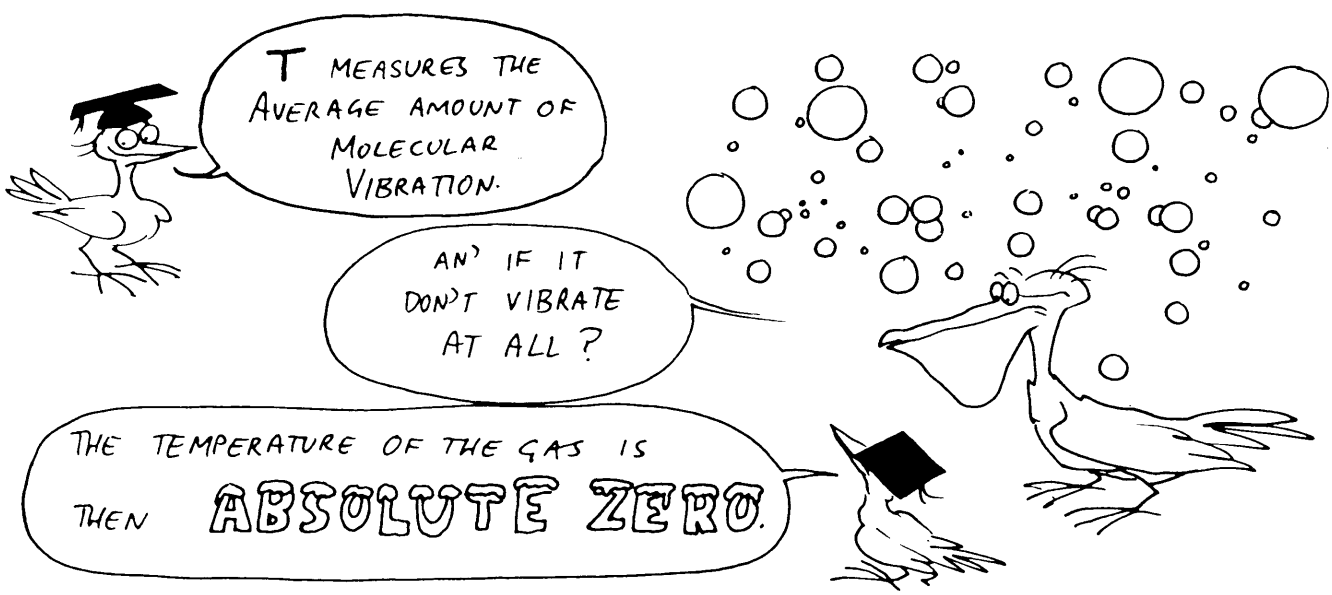
THERMAL ENERGY:



TEMPERATURE:

THE **ABSOLUTE TEMPERATURE** OF A GAS IS THE SIZE $T = \frac{1}{2} m V^2$ OF THE KINETIC ENERGY OF AGITATION OF A MOLECULE OF THE GAS.

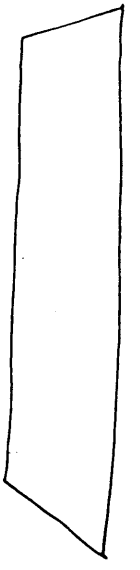
The Boss



YER CAN'T GET NO LOWER 'N THAT, CAN YER? YER CAN'T MOVE ANY LESS THAN NOT MOVIN' AT ALL, EH?

CRIKEY - I'VE UNDERSTOOD IT!

NO MOLECULAR VIBRATION - NO COLLISIONS ON WALLS - SO NO PRESSURE!



TO RECAP: THE MORE MOLECULES, THE MORE THEY HOP AROUND - WARM UP - AND THE HIGHER THE PRESSURE GETS

HEAT

WHEN AN OBJECT IS PLACED IN A FLUID, IT UNDERGOES AN ENORMOUS NUMBER OF MOLECULAR MICROSHOCKS. IN THIS WAY, THE MOLECULES CAN TRANSMIT OR EXCHANGE ENERGY, OR **HEAT**. THE POWER TO TRANSMIT HEAT INCREASES WITH THE DENSITY OF THE FLUID.

FOR THIS REASON, WATER IS A BETTER CONDUCTOR OF HEAT THAN AIR IS.

WHEN AN ASTRONAUT "WALKS" IN SPACE, HE MOVES IN A HIGHLY RAREFIED ATMOSPHERE (10 MOLECULES PER CUBIC CENTIMETER). THE DEGREE OF VIBRATION OF THE MOLECULES CORRESPONDS TO A TEMPERATURE OF 2500 °C – BUT THIS DOESN'T ROAST THE ASTRONAUT, BECAUSE THE AIR IS SO THIN THAT THE TOTAL HEAT TRANSMITTED IS SMALL

BRRR! 2500°C AND I'M FREEZING!

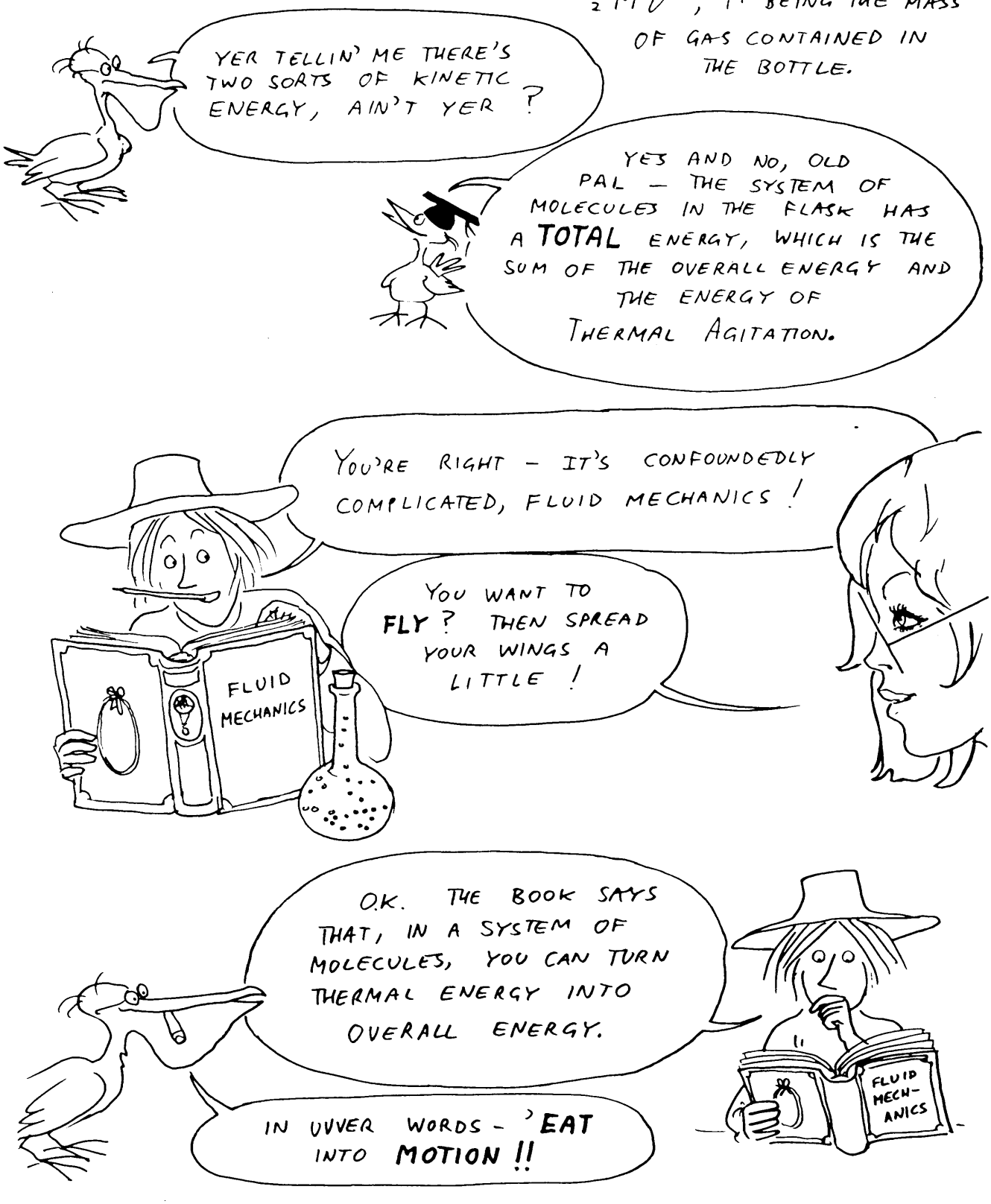
THE TEMPERATURE IS HIGH BUT THE HEAT FLUX IS FEEBLE.

OVERALL ENERGY

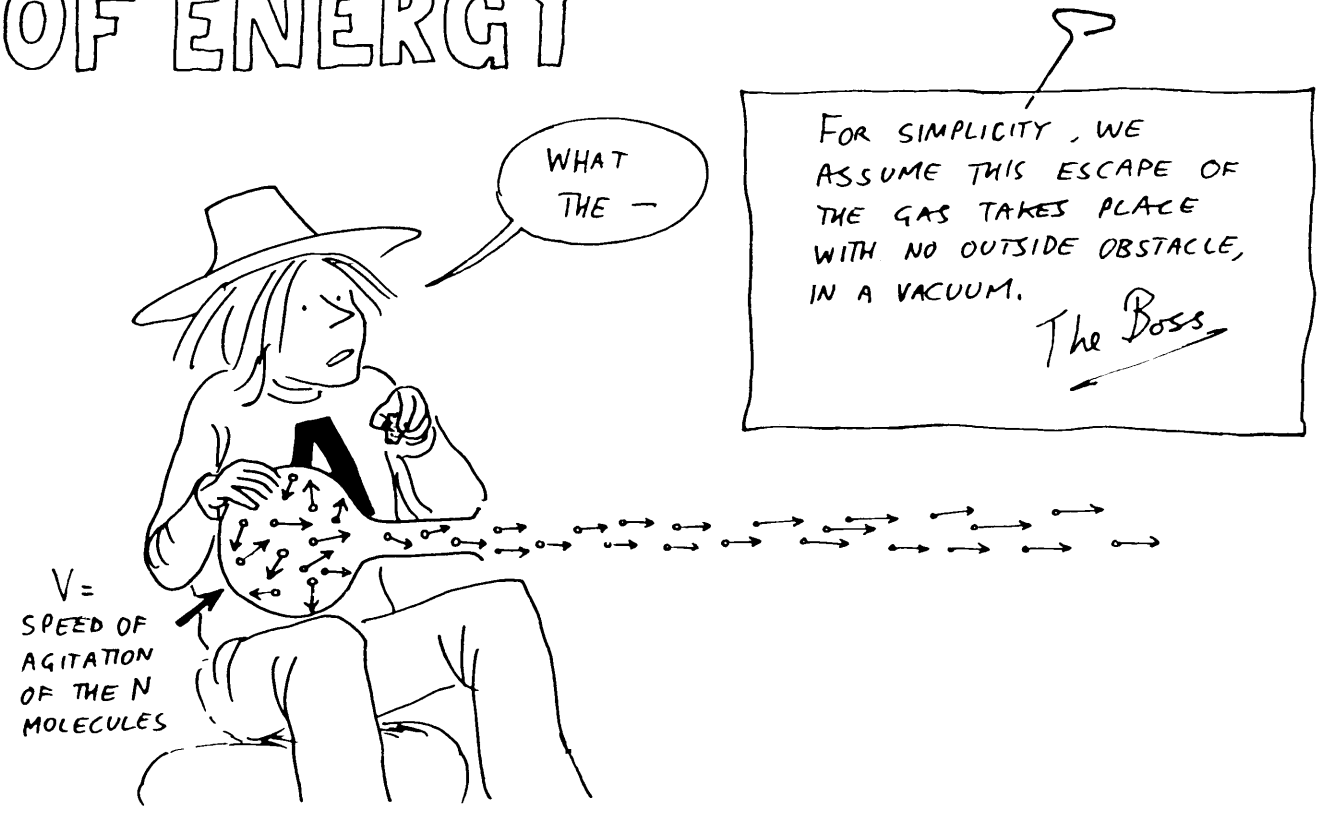
HERE IS A COLLECTION, A **SYSTEM** OF N MOLECULES, AT AN ABSOLUTE TEMPERATURE T.

ARCHIE THROWS THE BOTTLE OF GAS, GIVING IT AN **OVERALL VELOCITY** v.

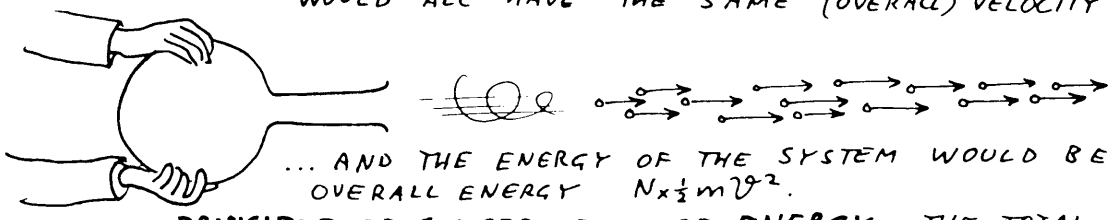
TO THIS OVERALL VELOCITY ϑ CORRESPONDS AN OVERALL KINETIC ENERGY $\frac{1}{2} M \vartheta^2$, M BEING THE MASS OF GAS CONTAINED IN THE BOTTLE.



CONSERVATION OF ENERGY



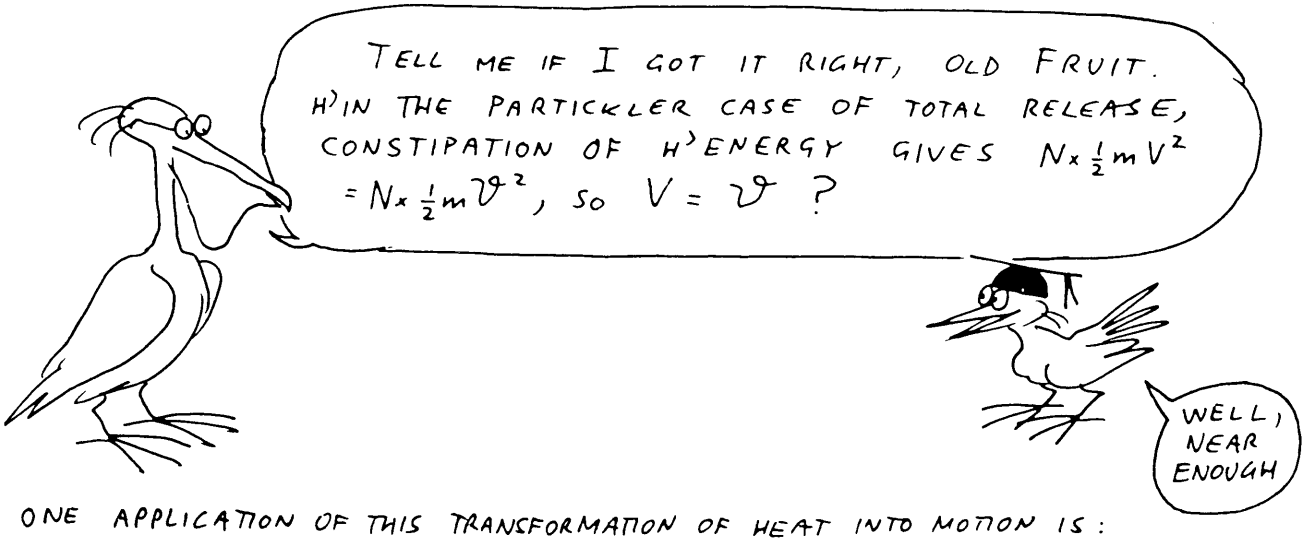
IF ALL THE HEAT WERE CHANGED INTO MOTION, THE MOLECULES WOULD ALL HAVE THE SAME (OVERALL) VELOCITY v...



... AND THE ENERGY OF THE SYSTEM WOULD BE THE OVERALL ENERGY $N \times \frac{1}{2} m v^2$.

BY THE **PRINCIPLE OF CONSERVATION OF ENERGY**, THE TOTAL ENERGY OF THE SYSTEM — THAT IS, THE SUM OF THE OVERALL ENERGY AND THE THERMAL ENERGY OF AGITATION — IS **CONSTANT** IN THIS PROCESS.

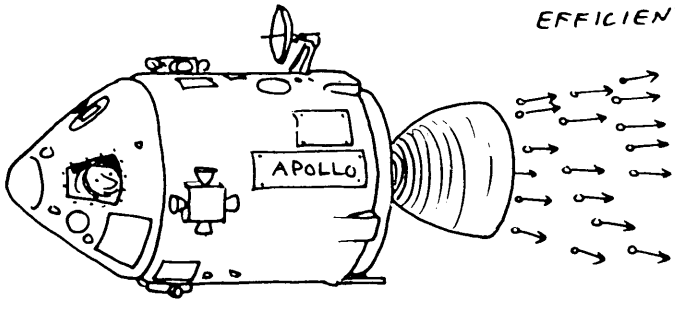
The Boss

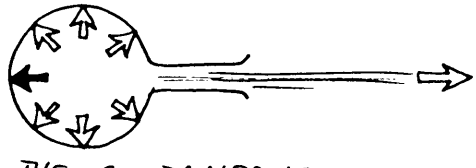


ONE APPLICATION OF THIS TRANSFORMATION OF HEAT INTO MOTION IS:

REACTION-PROPULSION

THE NOZZLE OF A ROCKET MOTOR, OR "EGGCUP," HAS A GEOMETRY WHICH REALIZES THE TRANSFORMATION HEAT ⇝ MOTION AS EFFICIENTLY AS POSSIBLE. THE PROPULSIVE FORCE ARISES BECAUSE, AS THE GAS ESCAPES, THE PRESSURE

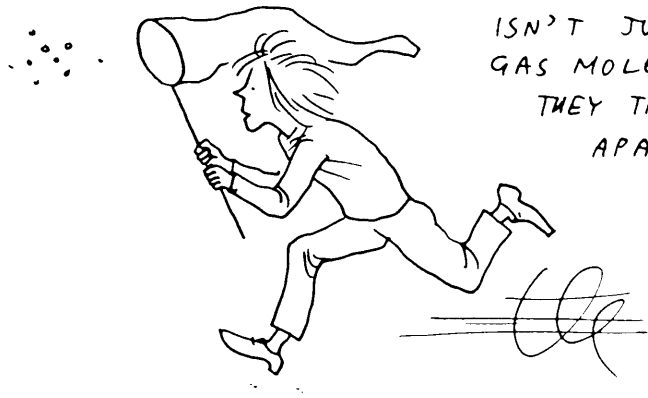




ON THE CONTAINER IS NO LONGER ZERO.


I SEE...
TO FLY, APPARENTLY, ALL YOU HAVE TO DO IS BLOW AIR DOWNWARDS...
LET'S GIVE IT A TRY.
HMMM... NOT VERY EFFECTIVE!
PSCHOOF!
LOOK, ARCHIE - BIRDS AREN'T SHAPED LIKE UMBRELLAS! DON'T WORRY, YOU'LL UNDERSTAND IT ALL PRETTY SOON. JUST CARRY ON...
MMMMM...
YOU'RE SO RIGHT, SOPHIE!

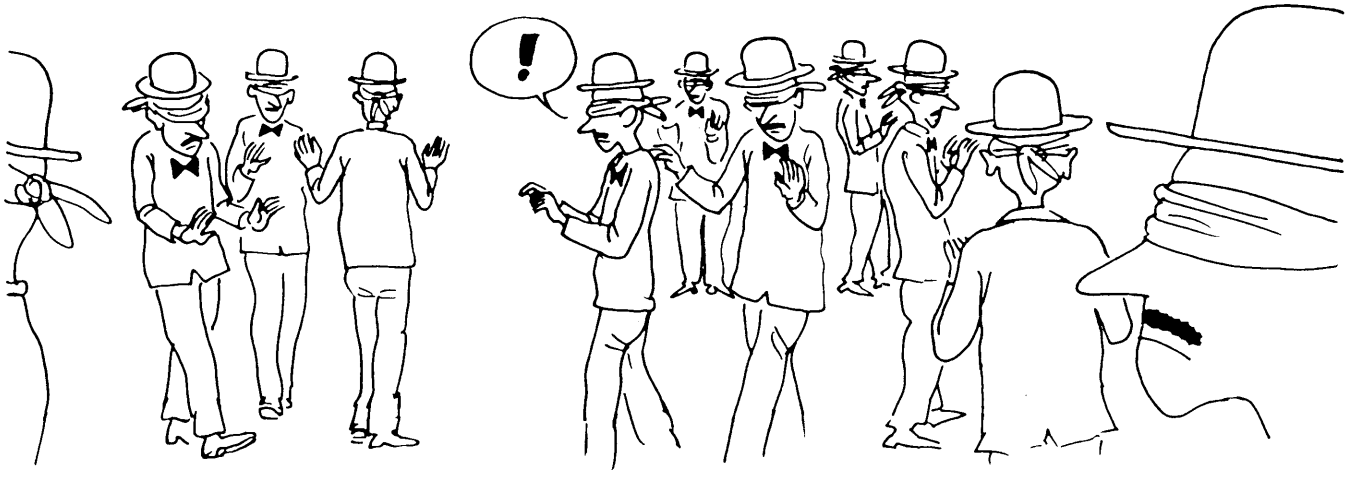
INCOMPRESSIBLE FLOW



THE EXPRESSION "FREE AS THE AIR" ISN'T JUST A HOLLOW PHRASE... GAS MOLECULES HATE CROWDS. THEY TRY TO STAY AS FAR APART AS POSSIBLE.

WHY DO THE MOLECULES GET OUT OF THE WAY AS SOON AS THE PADDLES COME TOGETHER?

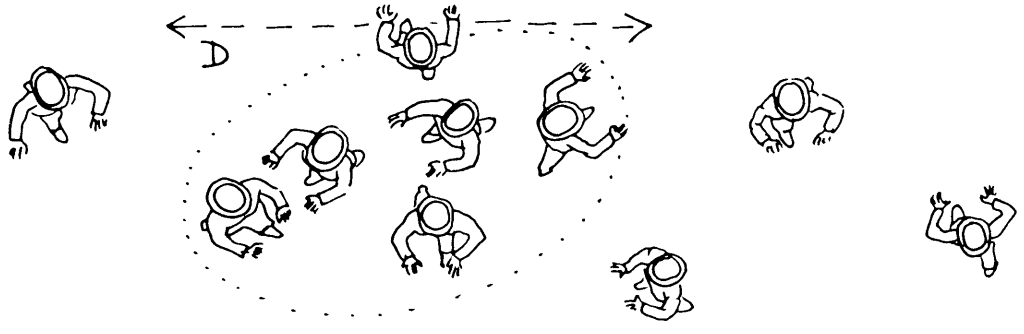
To see what the molecules are doing, imagine a place where everybody wanders around with blindfolds on. The people will play the role of molecules — and the speed they move at, haphazardly (more hazard than hap!) is the analog of the thermal agitation V.



They go nowhere in particular. Every t seconds, on average, after travelling a distance ℓ, they collide. We call ℓ the **mean free path** and t the **mean free travel time**.

In the atmosphere, V - the speed of thermal agitation - is about 340 m/second. The mean free path of a molecule is close to a hundred thousandth of a centimeter, so the time elapsing between two collisions of a molecule with its neighbors is only one ten thousand millionth of a second.

There is nothing to make these blindfolded people collect together. On the contrary — their random movements tend to disperse any group of diameter D in a time D/V.

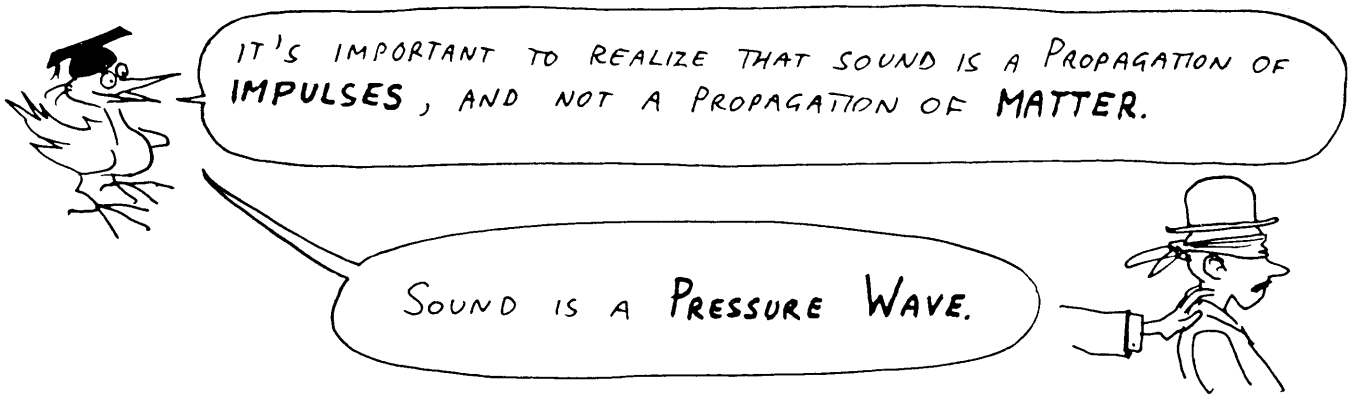


Essentially this is the time one person takes to move distance D - thereby leaving the group.

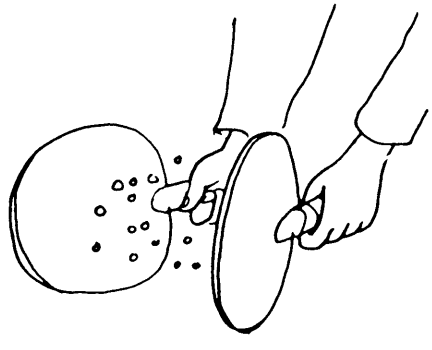
THESE PEOPLE - WHO WE ASSUME ARE ALSO STRUCK SPEECHLESS — CAN ONLY "SEE" AS FAR AS THEIR ARMS CAN REACH. IF SOMETHING MOVES INTO THE CROWD AT A SPEED v LOWER THAN THEIR SPEED OF MOVEMENT V, THEN THE PEOPLE CAN TELL EACH OTHER ABOUT IT, STEP BY STEP, BY BUMPING INTO EACH OTHER. SO THEY CAN GET OUT OF THE WAY **BEFORE** THE OBJECT HITS THEM.

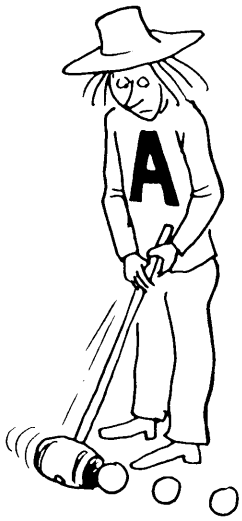
THIS INFORMATION MOVES AT THE SAME SPEED THEY DO — THAT IS, THE VELOCITY OF AGITATION V.

SOUND IS THE PROPAGATION, AT CONSTANT DENSITY, OF A PRESSURE - IMPULSE. IT'S A SORT OF WAVE OF JOSTLING, AND IT MOVES WITH A SPEED EQUAL TO V.



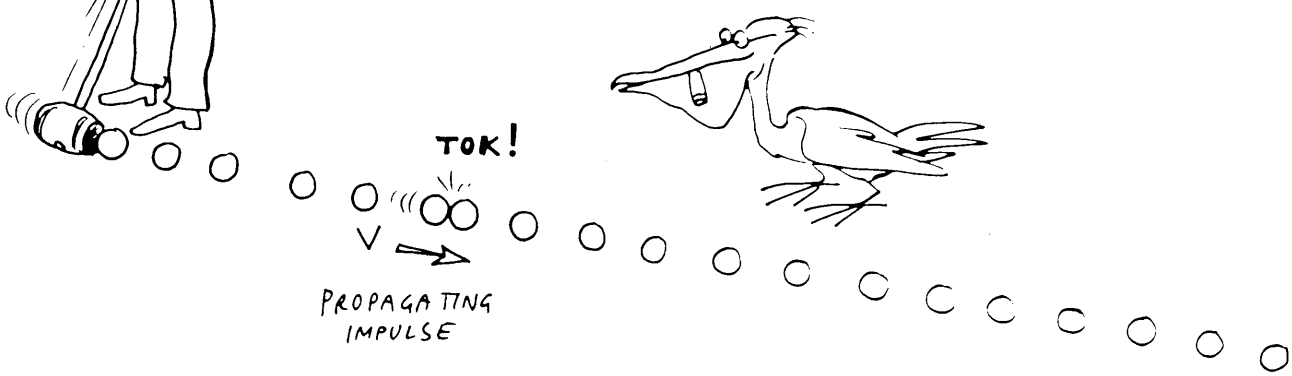
THE MOLECULES FLED FROM ARCHIE'S PADDLES AT THE SPEED OF SOUND. THEY COULD DO THIS EASILY WHILE MAINTAINING **CONSTANT DENSITY**, BECAUSE THE BATS WERE MOVING MUCH MORE SLOWLY THAN SOUND.



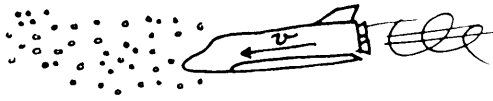


ARCHIE LINES UP SOME CROQUET BALLS. HE GIVES AN IMPULSE TO THE FIRST ONE, WHICH TRANSMITS IT TO THE SECOND, AND THIRD... AND SO ON.

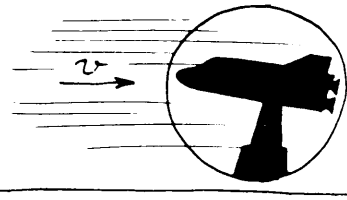
THIS IS A ONE-DIMENSIONAL IMAGE OF THE PROPAGATION OF SOUND.



THE NOTION OF SPEED IS **RELATIVE**. SO v CAN EQUALLY WELL BE THE SPEED OF AN OBJECT ENCOUNTERING A FLUID AT REST,



OR THE OVERALL VELOCITY OF GAS IMPINGING ON A **FIXED** OBJECT.



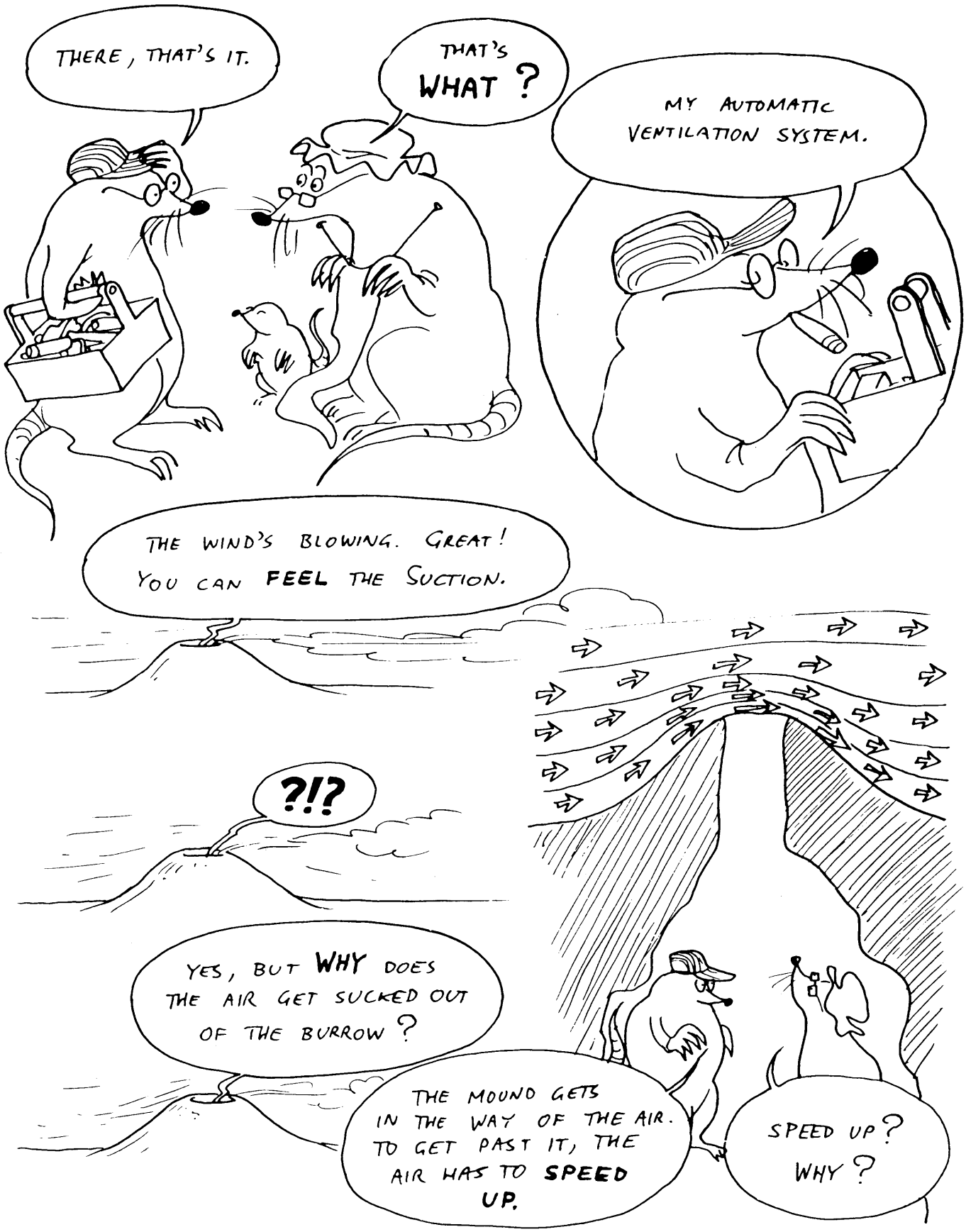
(WIND)

THE RATIO $\mathcal{M} = \frac{v}{V}$ WILL BE CALLED, BY DEFINITION, THE **MACH NUMBER**. V IS THE **SPEED OF SOUND**.

IF $v < V$, THAT IS, IF $\mathcal{M} < 1$, THE FLUID IS SAID TO BE IN THE **SUBSONIC REGIME**. THE FLOW TAKES PLACE AT CONSTANT DENSITY, AND IS SAID TO BE **INCOMPRESSIBLE**.

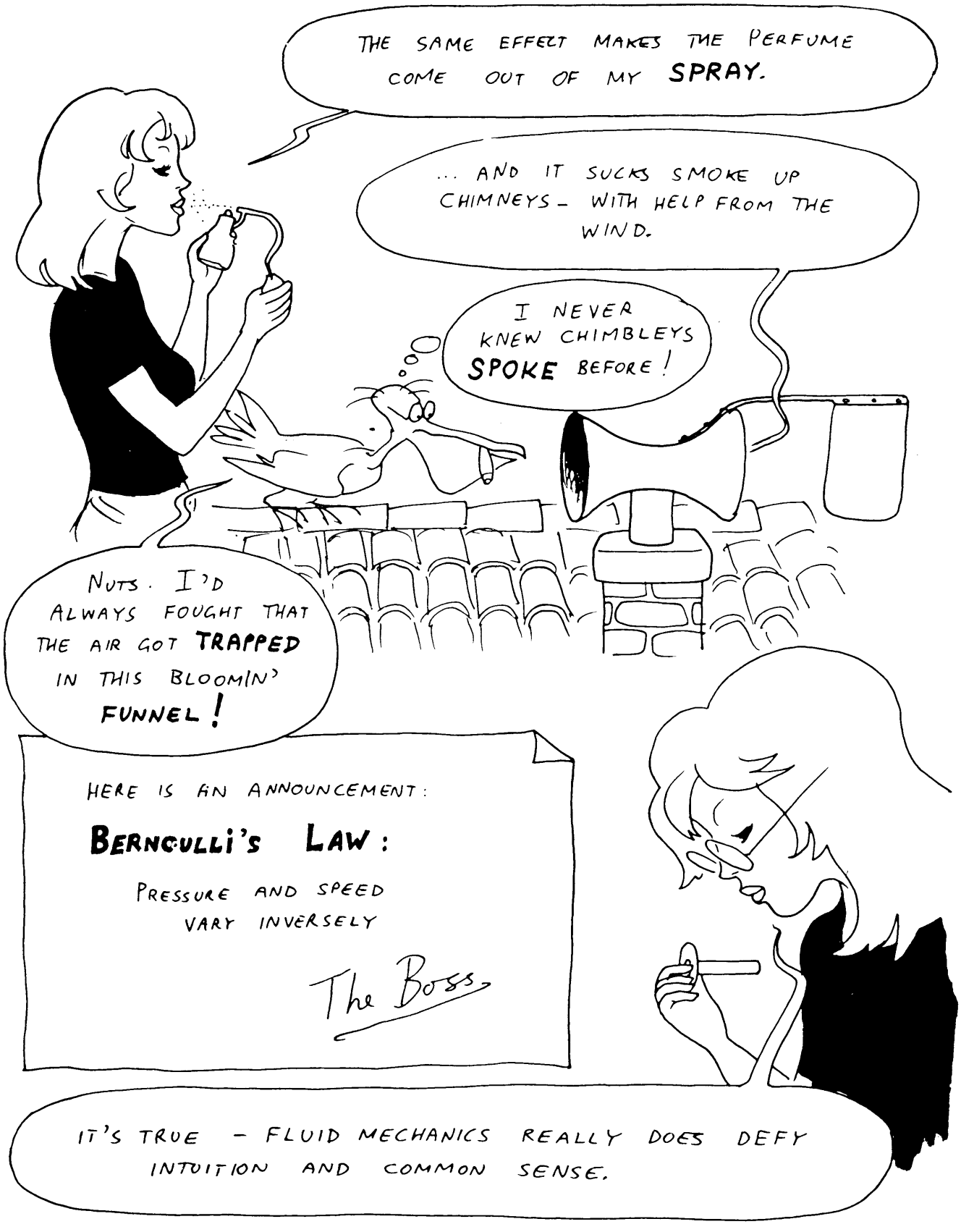
The Boss

BERNOULLI'S LAW


THERE, THAT'S IT.
THAT'S WHAT?
MY AUTOMATIC VENTILATION SYSTEM.
THE WIND'S BLOWING. GREAT! YOU CAN FEEL THE SUCTION.
?!?
YES, BUT WHY DOES THE AIR GET SUCKED OUT OF THE BURROW?
THE MOUND GETS IN THE WAY OF THE AIR. TO GET PAST IT, THE AIR HAS TO SPEED UP.
SPEED UP? WHY?

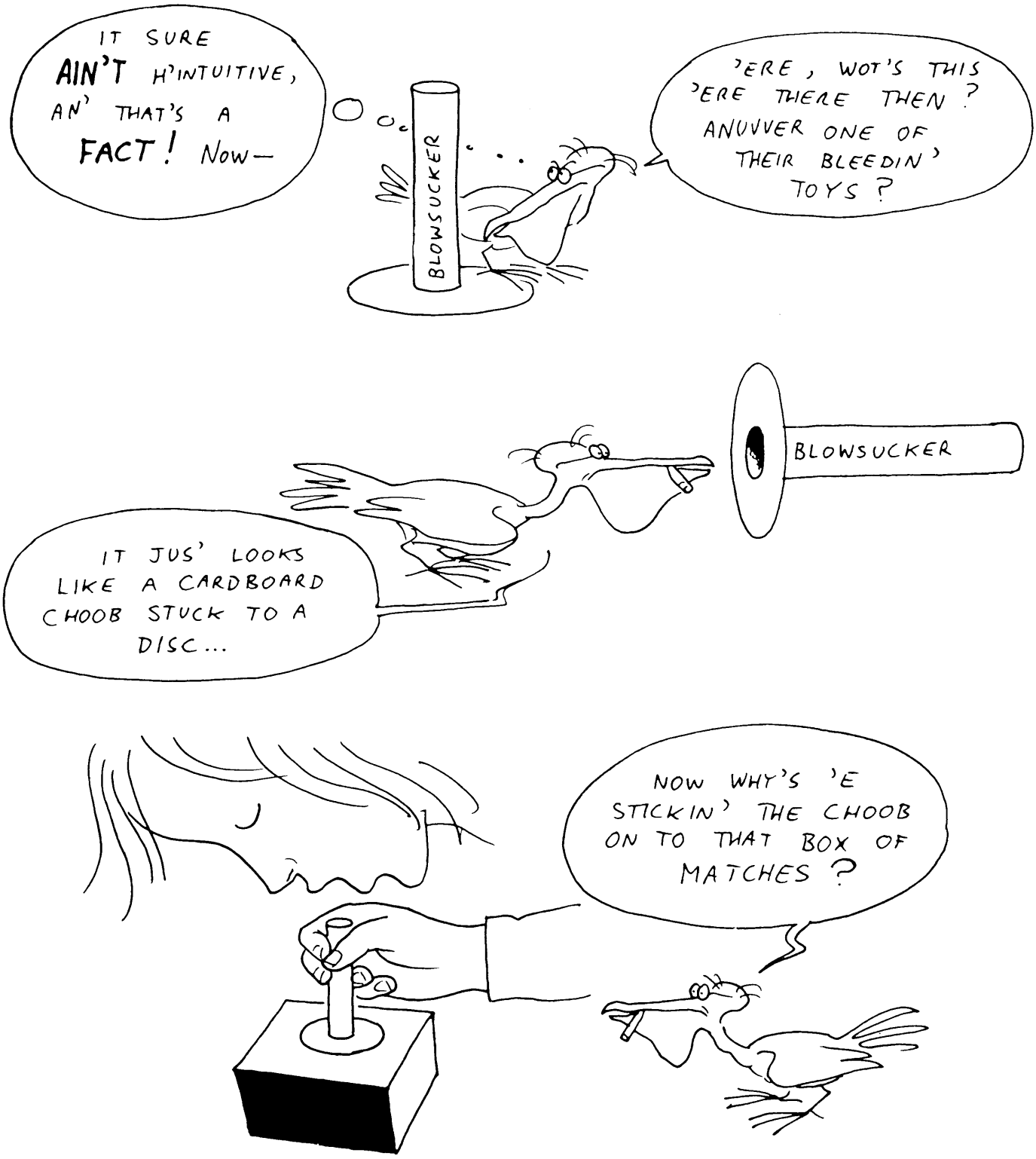

... LIKE RAPIDS ON A RIVER, WHEN IT NARROWS.
GOTCHA!
TO STOP THE FLOW FROM PILING UP...
O.K, SO IT GOES FASTER. BUT I STILL DON'T SEE HOW THE SUCTION ARISES.
LOOK AT A SMALL ELEMENT OF FLUID - A PACKAGE OF MOLECULES - PASSING THROUGH A CONSTRICTION LIKE THIS. ITS ENERGY STAYS CONSTANT. THE ACCELERATION HAS TO BE COMPENSATED BY A DROP IN THERMAL ENERGY - LESS AGITATION!
AND THAT MEANS THE PRESSURE DROPS.
YES, BECAUSE IT'S PROPORTIONAL TO THE TEMPERATURE, WHICH IS THE THERMAL AGITATION.
AND THAT'S WHAT SUCKS THE AIR OUT OF THIS HOLE.

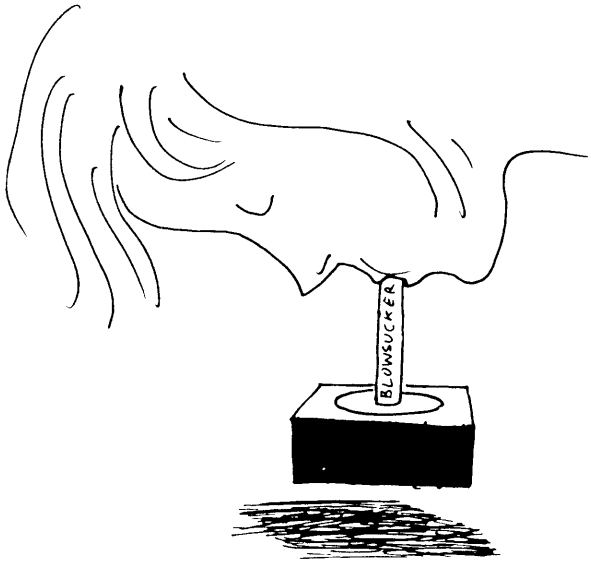

HOW HAVE YOU MANAGED TO BECOME SO KNOWLEDGEABLE?
OH, I'VE BURROWED INTO A LOT OF THINGS!
IT'S FUNNY — WHEN WE STOP THE ROOF IS ALL SLACK AND HANGS DOWN INSIDE; BUT NOW THAT WE'RE MOVING IT'S SWOLLEN OUTWARDS!
AND YET THE AIR IS PUSHING AGAINST IT.
IT'S JUST LIKE THE MOLEHILL. YOU KNOW, THIS CAR LOOKS QUITE LIKE ONE, DOESN'T IT?
OH — SO THE AIR HAS TO ACCELERATE TO GET PAST THE CAR AT CONSTANT DENSITY. THEN THE TEMPERATURE DROPS, THE PRESSURE DOES TOO — AND THE ROOF SWELLS. I SEE NOW.

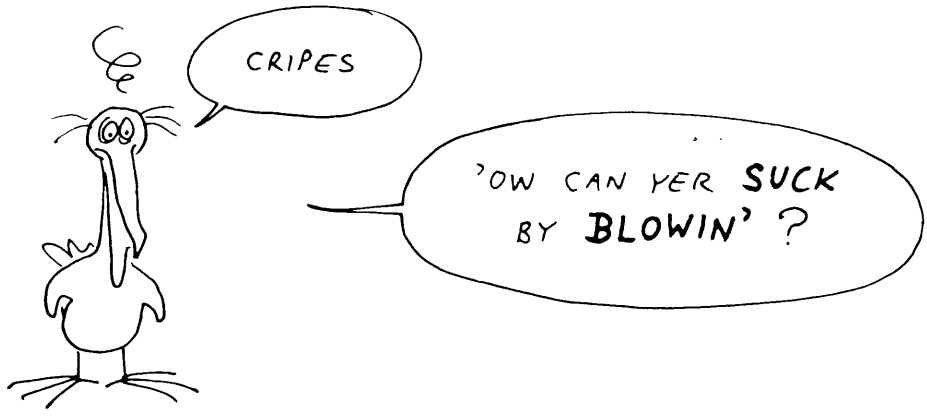

THE SAME EFFECT MAKES THE PERFUME COME OUT OF MY SPRAY.
... AND IT SUCKS SMOKE UP CHIMNEYS - WITH HELP FROM THE WIND.
I NEVER KNEW CHIMBLEYS SPOKE BEFORE!
NUTS. I'D ALWAYS FOUGHT THAT THE AIR GOT TRAPPED IN THIS BLOOMIN' FUNNEL!
HERE IS AN ANNOUNCEMENT:
BERNOULLI'S LAW:
PRESSURE AND SPEED VARY INVERSELY
The Boss
IT'S TRUE - FLUID MECHANICS REALLY DOES DEFY INTUITION AND COMMON SENSE.

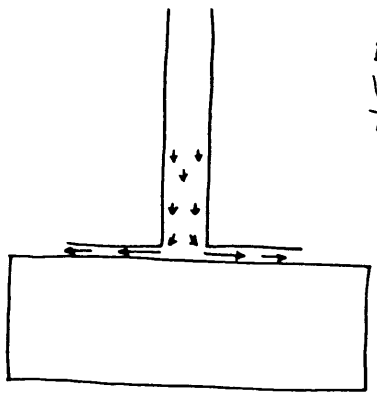
EXAMPLE OF A

PARADOX RELATED TO BERNOULLI'S LAW...



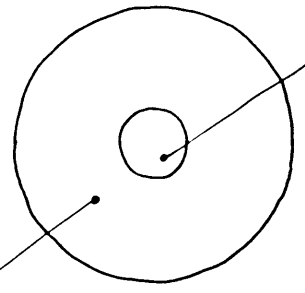




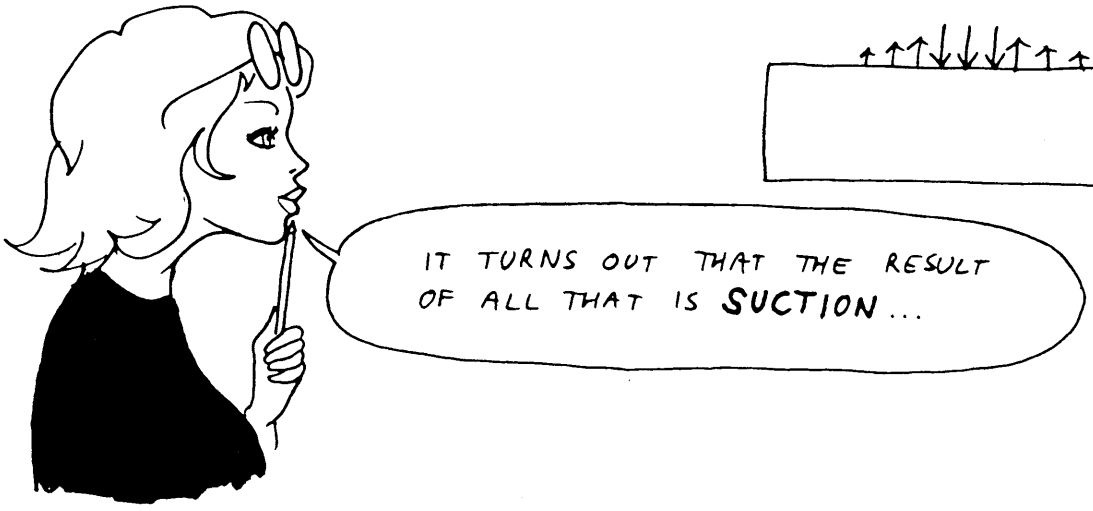


... THE OUTSIDE PART IS AT A **LOWER** PRESSURE THAN THE ATMOSPHERE.

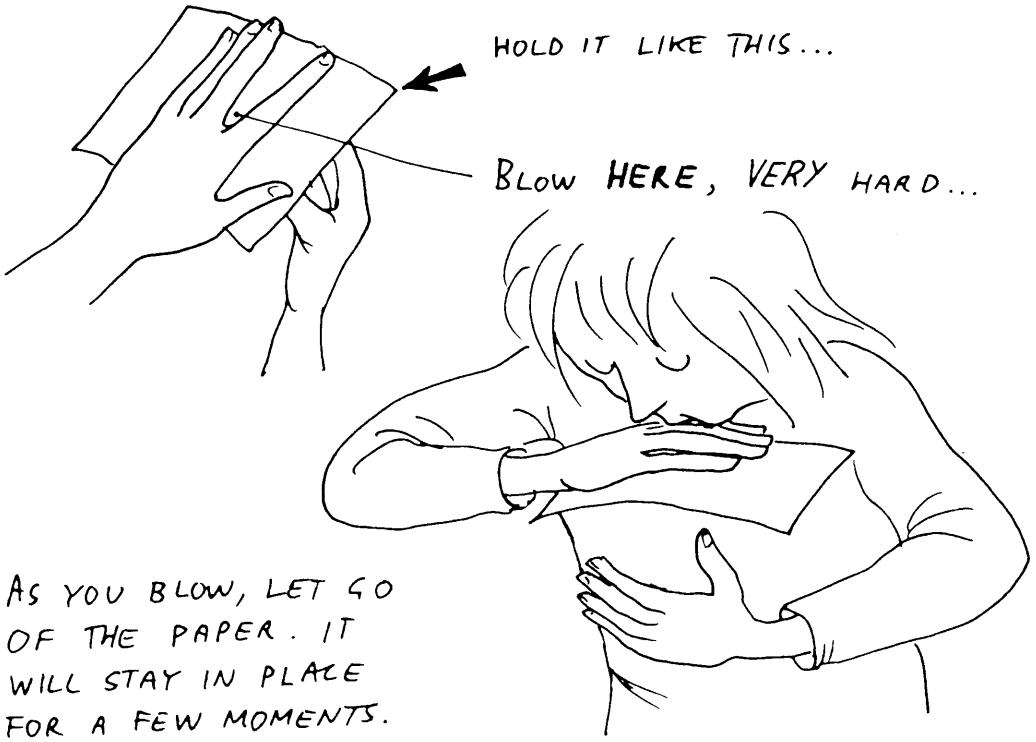
AT THE JUNCTION OF THE CYLINDER AND THE DISC, THE WIDTH FOR THE GAS TO PASS THROUGH DROPS SUDDENLY, AND THE AIR SPEEDS UP VIOLENTLY. THE PRESSURE DROPS BELOW THAT OF THE ATMOSPHERE.



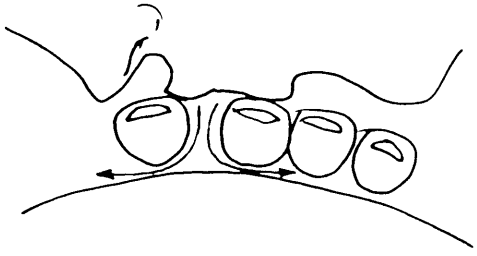
THE PART OF THE BOX OPPOSITE THE HOLE IN THE TUBE IS AT A HIGHER PRESSURE THAN ITS SURROUNDINGS...



YOU CAN PRODUCE A SIMILAR EFFECT USING ONLY A SHEET OF PAPER.



AS YOU BLOW, LET GO OF THE PAPER. IT WILL STAY IN PLACE FOR A FEW MOMENTS.



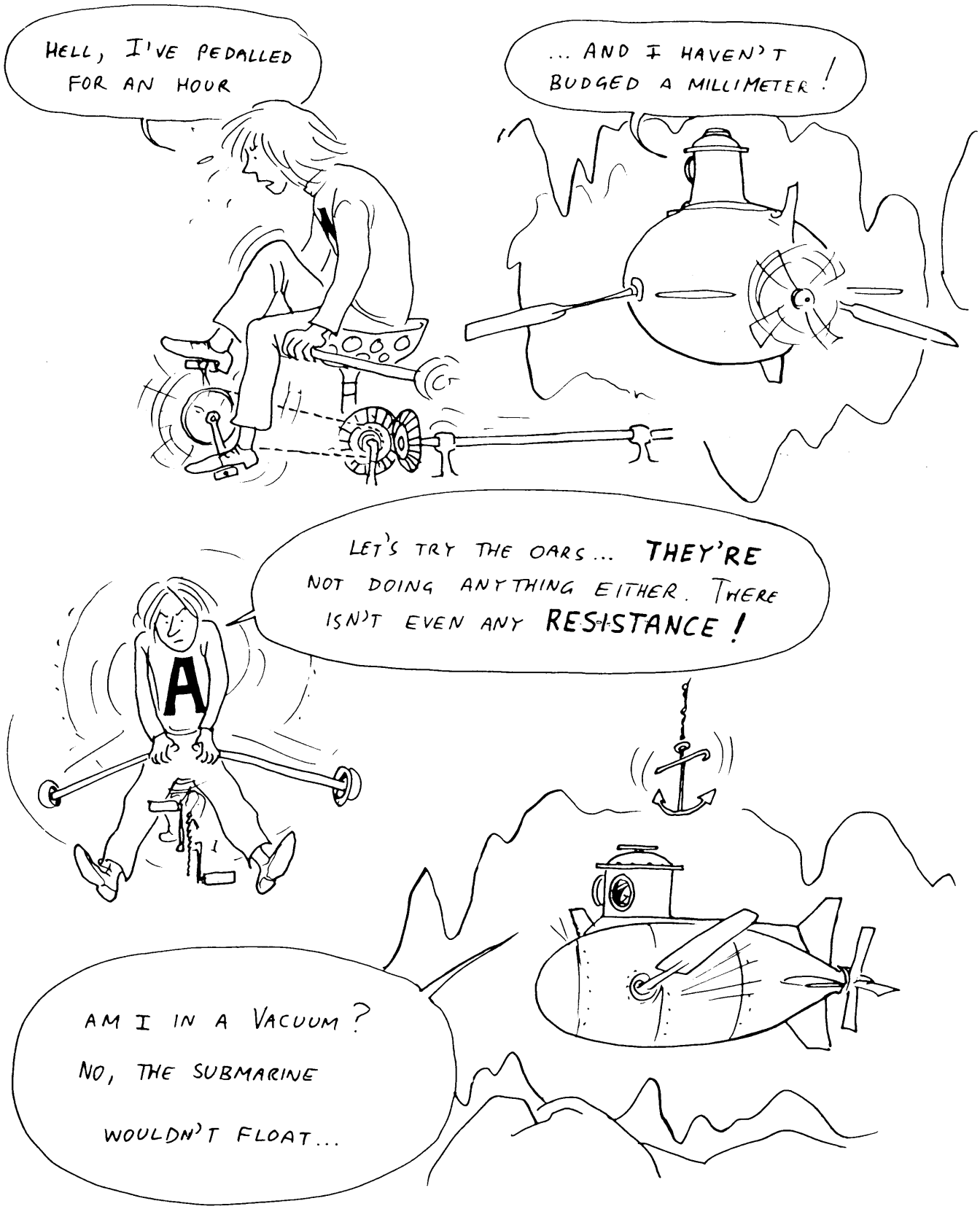
N.B.

BLOW HARD!!

The Boss


HOW ABOUT COMING FOR A FLIGHT ?
ARTER WOT I SEEN TODAY, MATE, I'D RATHER WALK !!!
FLUID, DENSITY, PRESSURE, TEMPERATURE , REACTION, BERNOULLI – I SHOULD HAVE ALL THE WORDS I NEED TO GET OFF THE GROUND.
TEMPERATURE
REACTION
BERNOULLI
A
DENSITY
PRESSURE
?
NO, THERE'S ONE MISSING.
WHICH ?

ARCHIBALD'S DREAM:


HELL, I'VE PEDALLED FOR AN HOUR
... AND I HAVEN'T BUDGED A MILLIMETER!
LET'S TRY THE OARS... THEY'RE NOT DOING ANYTHING EITHER. THERE ISN'T EVEN ANY RESISTANCE!
A
AM I IN A VACUUM?
NO, THE SUBMARINE WOULDN'T FLOAT...


CRIKEY, IT LOOKS LIKE I'M SURFACING!
!..
BY ALL THE WIND-DEVILS OF HELL, SOPHIE - WHAT'S BEEN GOING ON?
SUPERFLUID
HELIUM


YOU WERE JUST IN SOME SUPERFLUID HELIUM. REMEMBER WHAT HAPPENED IN THE SANDBOX? THE FRICTION OF THE GRAINS OF SAND AGAINST EACH OTHER WAS SO GREAT THAT THE SAND ONLY FLOWED WITH DIFFICULTY.
HERE IT'S THE OPPOSITE. BELOW A CERTAIN VERY LOW TEMPERATURE, THE FLUIDITY OF HELIUM BECOMES INFINITE, AND THERE IS NO FRICTION AT ALL.
BUT WHAT'S FRICTION GOT TO DO WITH ROWING, FLYING, OR PROPELLING YOURSELF WITH A PROPELLER?
YOU HAD THE IDEA, IN A WAY, WITH YOUR UMBRELLA. TO GET SUPPORT FROM THE AIR YOU HAVE TO GRAB HOLD OF IT.
IF THE AIR WERE SUPERFLUID, YOUR PARACHUTE WOULDN'T BE ANY USE. WORSE – IT WOULDN'T OPEN, AND YOU'D FALL LIKE A STONE.

THE FIRST CREATURE WHO TRIED TO REACH FOR THE SKY QUICKLY FOUND OUT THAT ONE WAY OR ANOTHER, IT WOULD HAVE TO GRAB THE AIR...

SO THE FLIGHT OF A HEAVIER-THAN-AIR DEVICE IS LIKE AN ENDLESS ATTEMPT TO GAIN A HOLD ON SOMETHING SO TENUOUS THAT IT ALWAYS SLIPS FROM YOUR GRASP.

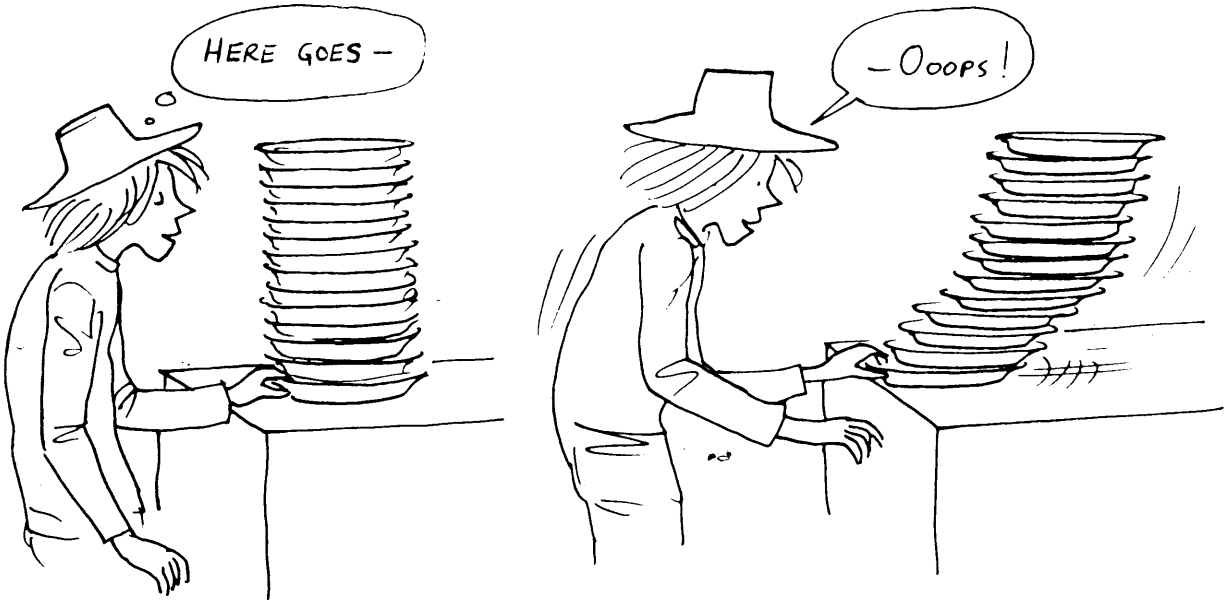
SO YOU HAVE TO FIND SOME WAY TO GET SUPPORT FROM SUCH A MEDIUM.

IF IT'S SUPERFLUID, THE MOLECULES SLIP PAST EACH OTHER, AND PAST OBJECTS, WITH NO FRICTION.

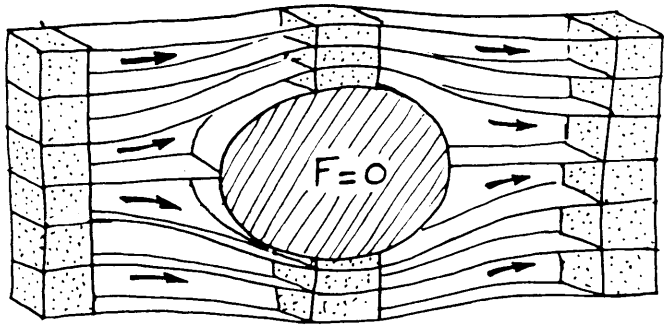
THE BIRDS WOULD HAVE TO GO ON FOOT, WINDMILLS WOULDN'T TURN, AND AERIAL TRANSPORT WOULD HAVE TO BE ACHIEVED USING BALLOONS WITH REACTION MOTORS.

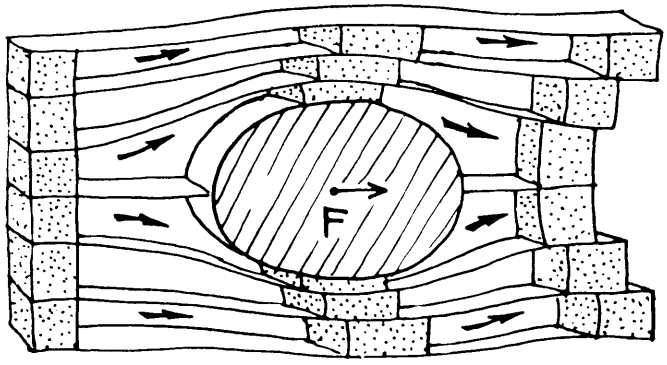
FLYING THUS DEPENDS ON GASEOUS FRICTION.

VISCOUS FLUIDS



LIKE THESE PLATES, THE SUPERIMPOSED LAYERS OF GAS DO NOT SLIDE OVER EACH OTHER WITHOUT FRICTION.



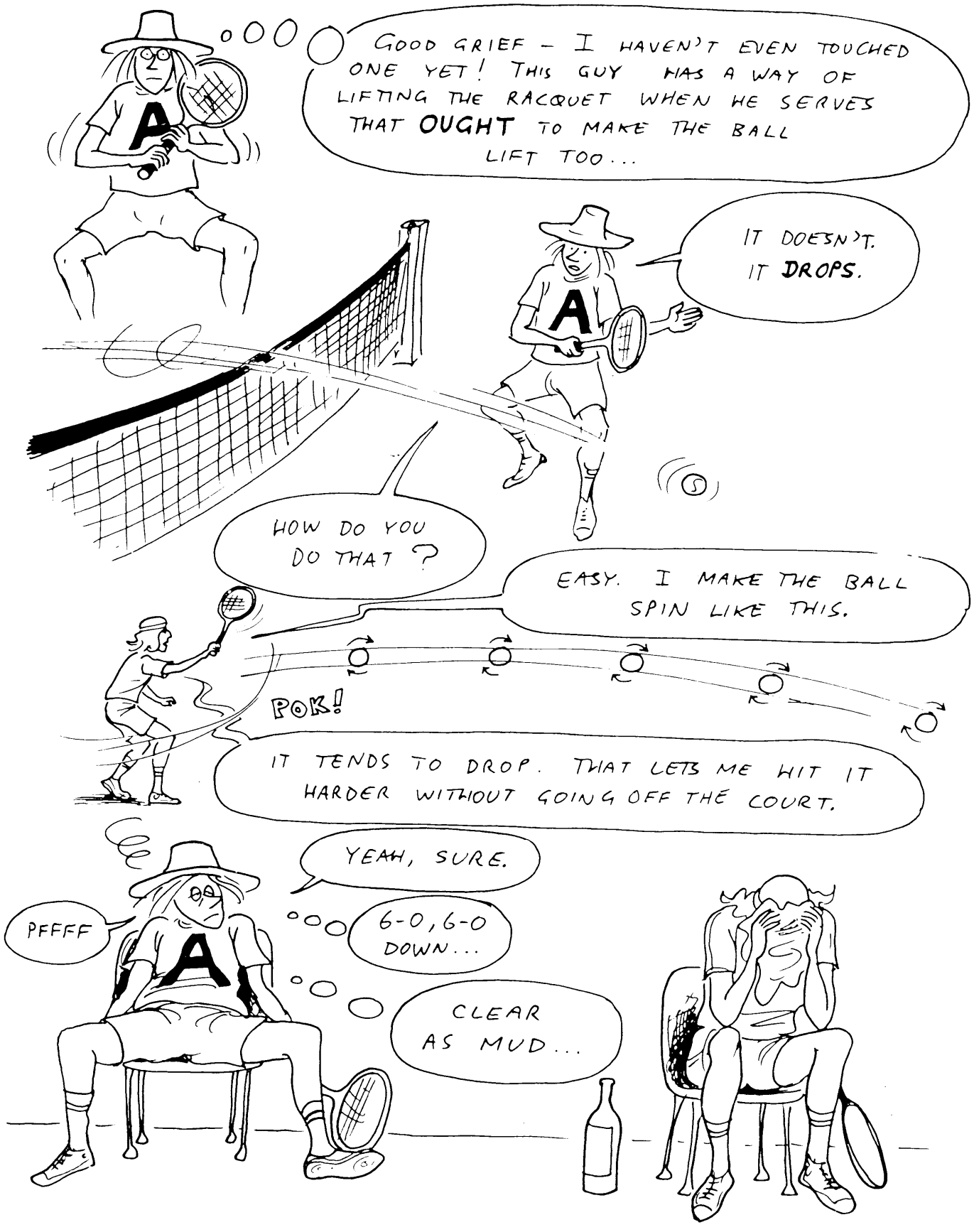


IMAGINE A FIXED OBJECT IN A STREAM OF GAS MOLECULES, WHICH WE CAN REPRESENT BY LITTLE CUBICAL BOXES.

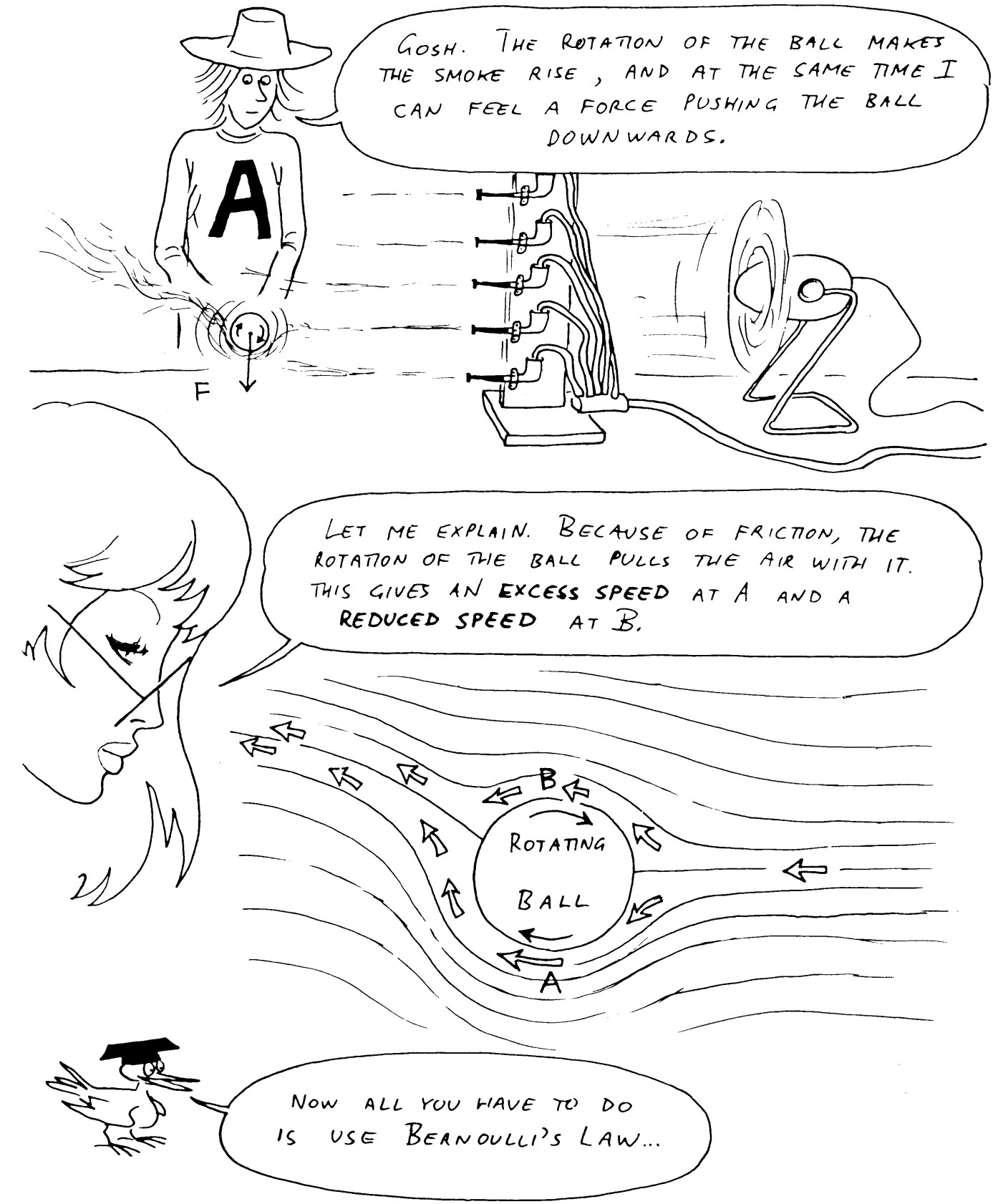
- IN THE ABSENCE OF ANY FRICTION, AFTER CIRCUMNAVIGATING THE OBJECT, THE MOLECULES END UP PILED ON TOP OF EACH OTHER LIKE THEY WERE AT THE START.
- IN CONTRAST, FRICTION SLOWS DOWN MOLECULES THAT PASS CLOSE TO THE OBJECT DOWNSTREAM, THE BOXES ARE SHIFTED, THE OBJECT SLOWS THE GAS DOWN, AND CONVERSELY THE GAS EXERTS A FORCE F ON THE OBJECT:

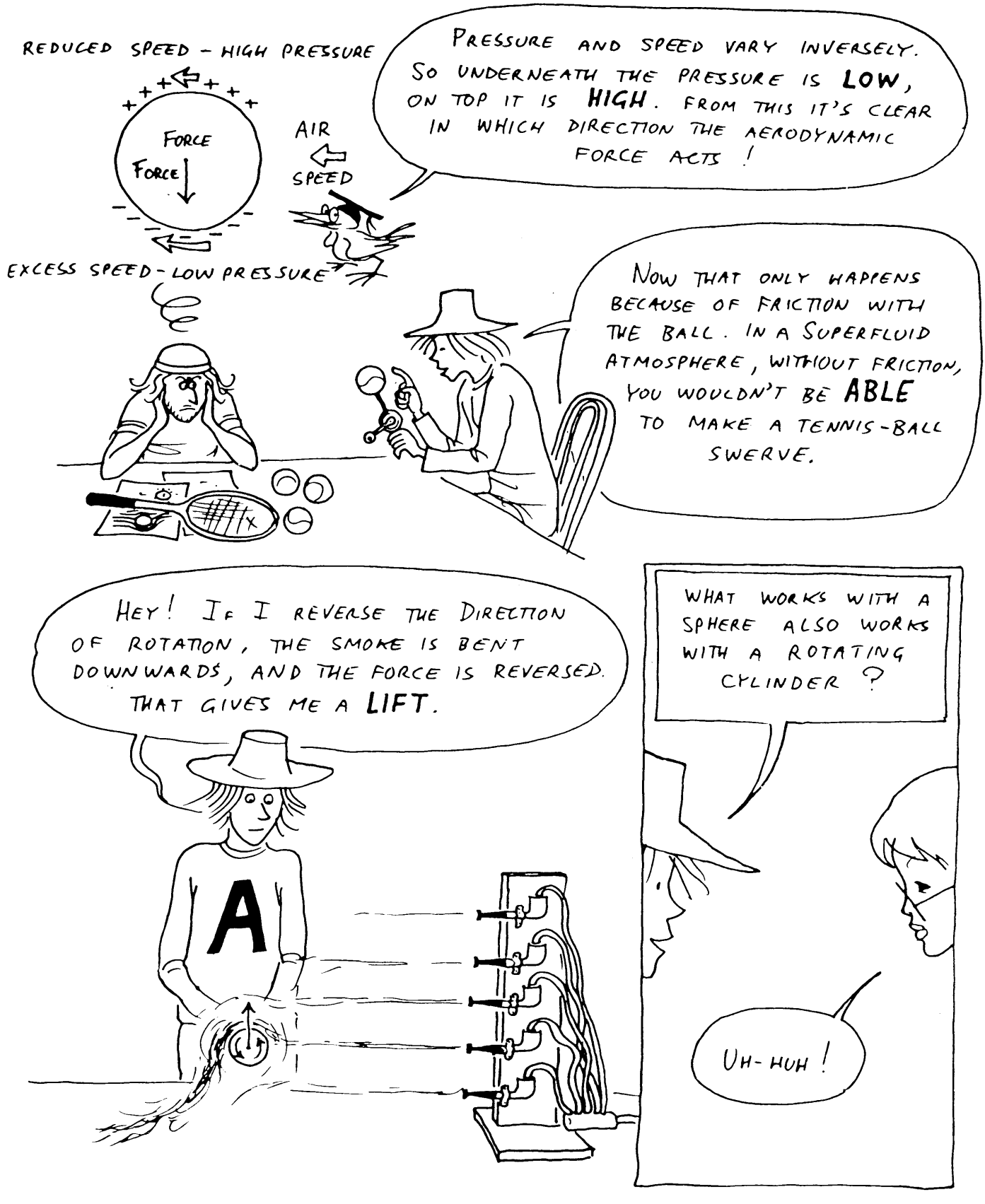
FRICTIONAL DRAG.


IT'S ALL TOO COMPLICATED FOR ME. I THINK I'LL RELAX A BIT AND PLAY SOME TENNIS. THE MECHANICS OF THAT, AT LEAST, IS EASY. BALLISTICS. YOU HIT THE BALL – BOOM! AND IF YOU'VE CALCULATED IT CORRECTLY, IT LANDS IN THE COURT.
SWERVICE GAME...
I'LL PUT MY NAME DOWN FOR A GAME ... GOOD, HERE'S A SPARE PLACE. BJÖRN BORG ... DON'T KNOW HIM.
READY?
CHPOK!

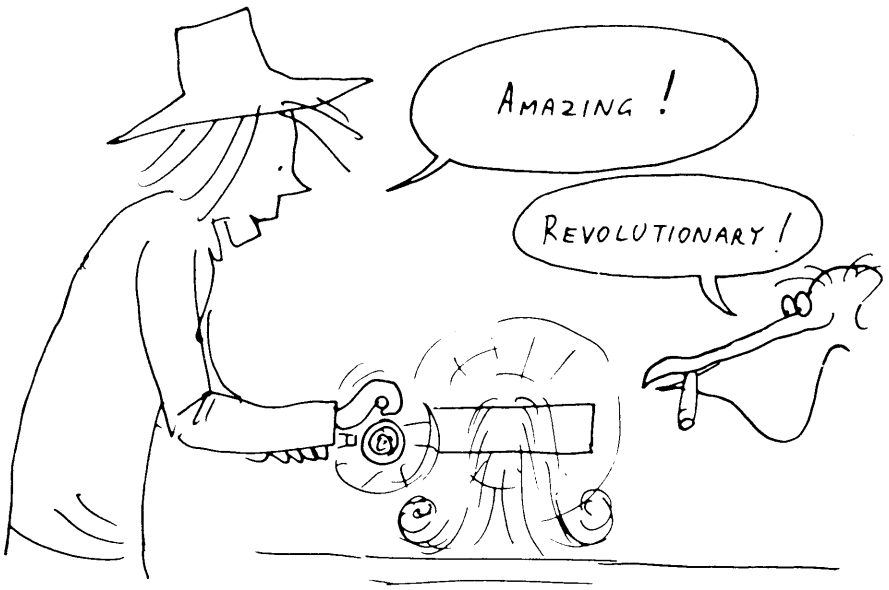

GOOD GRIEF – I HAVEN'T EVEN TOUCHED ONE YET! THIS GUY HAS A WAY OF LIFTING THE RACQUET WHEN HE SERVES THAT OUGHT TO MAKE THE BALL LIFT TOO...
IT DOESN'T. IT DROPS.
HOW DO YOU DO THAT?
EASY. I MAKE THE BALL SPIN LIKE THIS.
POK!
IT TENDS TO DROP. THAT LETS ME HIT IT HARDER WITHOUT GOING OFF THE COURT.
YEAH, SURE.
PFFFF
6-0, 6-0 DOWN...
CLEAR AS MUD...


LET'S SEE. BORG SENT THE BALL FROM LEFT TO RIGHT IN THE PICTURE ON THE LAST PAGE. I'LL MAKE THE AIR HIT THE BALL FROM RIGHT TO LEFT – THAT OUGHT TO COME TO THE SAME THING.
ARCHIE BUILDS A WIND-TUNNEL.
YOU SEE, SOPHIE, THE SMOKE FROM THE PIPES MAKES THE AIRSTREAM VISIBLE.
NOW ALL I NEED IS TO MAKE SURE THE BALL WILL ROTATE. THIS OUGHT TO DO IT...
YES - THAT WHISKS IT AROUND BEAUTIFULLY!

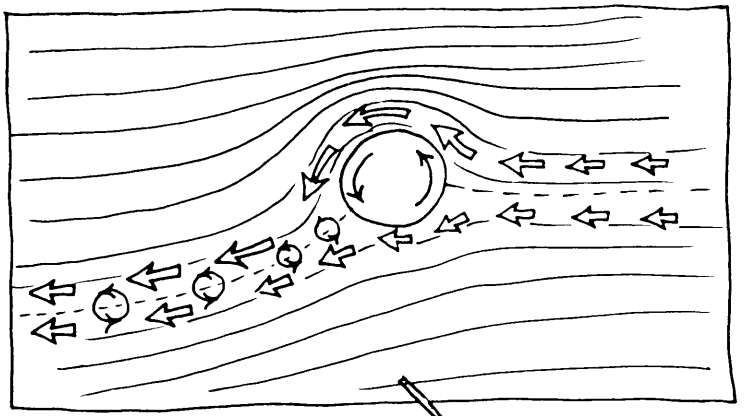

GOSH. THE ROTATION OF THE BALL MAKES THE SMOKE RISE, AND AT THE SAME TIME I CAN FEEL A FORCE PUSHING THE BALL DOWNWARDS.
A
F
LET ME EXPLAIN. BECAUSE OF FRICTION, THE ROTATION OF THE BALL PULLS THE AIR WITH IT. THIS GIVES AN **EXCESS SPEED** AT A AND A **REDUCED SPEED** AT B.
B
ROTATING BALL
A
NOW ALL YOU HAVE TO DO IS USE BERNOULLI'S LAW...


REDUCED SPEED - HIGH PRESSURE
FORCE
FORCE
AIR
SPEED
EXCESS SPEED - LOW PRESSURE
PRESSURE AND SPEED VARY INVERSELY. SO UNDERNEATH THE PRESSURE IS LOW, ON TOP IT IS HIGH. FROM THIS IT'S CLEAR IN WHICH DIRECTION THE AERODYNAMIC FORCE ACTS!
NOW THAT ONLY HAPPENS BECAUSE OF FRICTION WITH THE BALL. IN A SUPERFLUID ATMOSPHERE, WITHOUT FRICTION, YOU WOULDN'T BE ABLE TO MAKE A TENNIS-BALL SWERVE.
HEY! IF I REVERSE THE DIRECTION OF ROTATION, THE SMOKE IS BENT DOWNWARDS, AND THE FORCE IS REVERSED. THAT GIVES ME A LIFT.
A
WHAT WORKS WITH A SPHERE ALSO WORKS WITH A ROTATING CYLINDER?
UH-HUH!

THE FLETTNER ROTOR



LADIES, GENTLEMEN, AND OTHERS – LET US LOOK MORE CLOSELY IN THE **WAKE** OF THIS DISCOVERY. THE ROTATION OF THE CYLINDER PRODUCES DIFFERENT SPEEDS IN THE FLOWS OVER THE TOP AND UNDERNEATH.



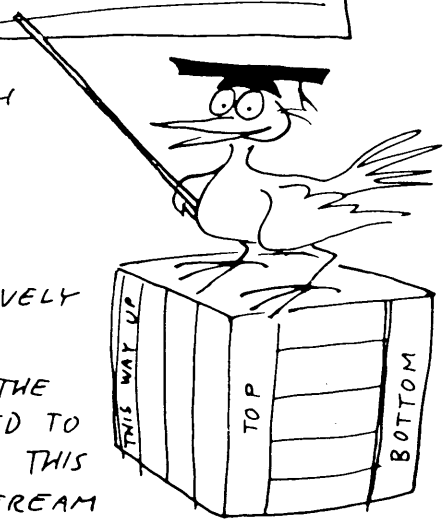
DOWNSTREAM FROM THE CYLINDER, ALTHOUGH THE TWO LAYERS OF AIR JOIN UP AGAIN, THEY RUB AGAINST EACH OTHER.

AS A RESULT:

a) TINY EDDIES FORM.

b) THE DIFFERENCE IN SPEED IS PROGRESSIVELY DIMINISHED.

THERE IS A PRESSURE DIFFERENCE BETWEEN THE TOP OF THE LAYER AND THE BOTTOM, RELATED TO THE DIFFERENCE IN THE SPEEDS (BERNOULLI). THIS IS WHY THE AIRSTREAM IS CURVED, DOWNSTREAM OF THE ROTOR.




A
BY ROTATING A CYLINDER IN THE AIR, I'VE MANAGED TO GET SOME LIFT. THAT GIVES ME AN IDEA! I OUGHT TO BE ABLE TO MAKE A FLYING MACHINE.
KLONK
KLONK
SWWWIIII
I'M TRYING TO ADAPT MY REACTION MOTOR.
WOT'S 'E MUCKIN' ABART WIV NOW?
IT LOOKS FIENDISHLY COMPLICATED.

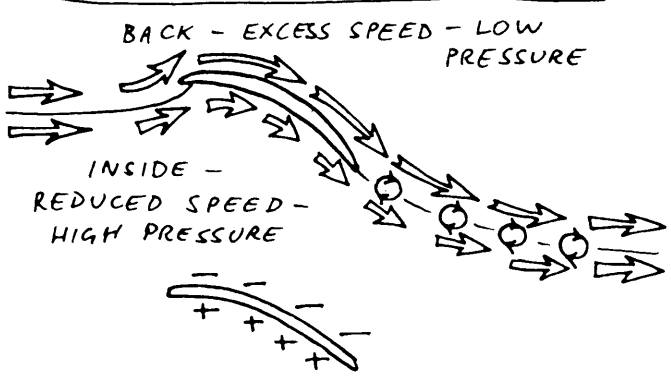
(*) IF THE POWER IS HIGH ENOUGH, IT ACTUALLY WORKS VERY WELL !

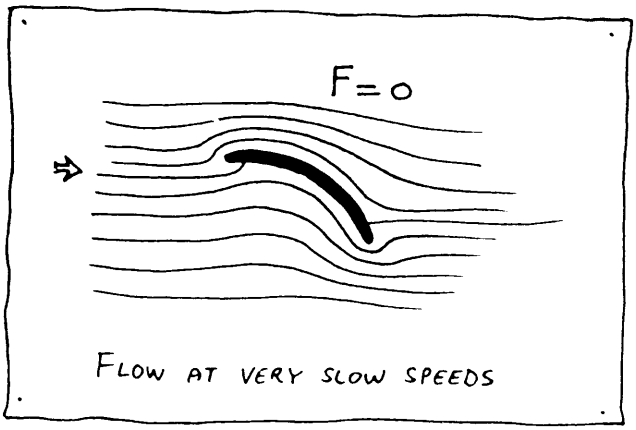

YIKES! WHAT'S HAPPENING? I'M GOING INTO A DIVE!
01
ONLY TO BE EXPECTED, ARCHIE. YOU MAKE THE AIR TURN, SO THE MACHINE HAS A TENDENCY TO TURN THE OTHER WAY.
IT'S THE PRINCIPLE OF ACTION AND REACTION.
THE PRINCIPLE OF WHAT?
OH, ARCHIE - WHY DIDN'T YOU ASK ME FIRST? THERE'S A MUCH SIMPLER WAY - BUT YOU ALWAYS HAVE TO DO IT ON YOUR OWN, DON'T YOU? COME ON, THE COFFEE'S READY.

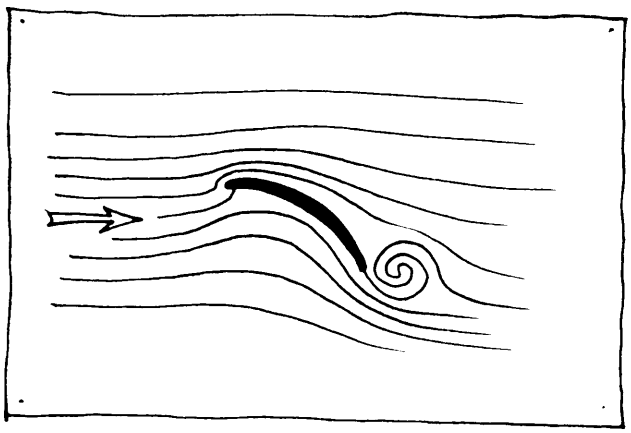

AH, THOSE PRECIPITATE MEN IN THEIR FLYING-MACHINES!
IT'S FUNNY, WHAT YOU CAN SEE IN A CUP OF COFFEE.
IF I MOVE THE SPOON VERY GENTLY, I CAN ONLY FEEL A TINY AMOUNT OF RESISTANCE, DUE TO FRICTION...
... BUT IF I MOVE IT QUICKLY, AN EDDY BREAKS AWAY FROM IT.

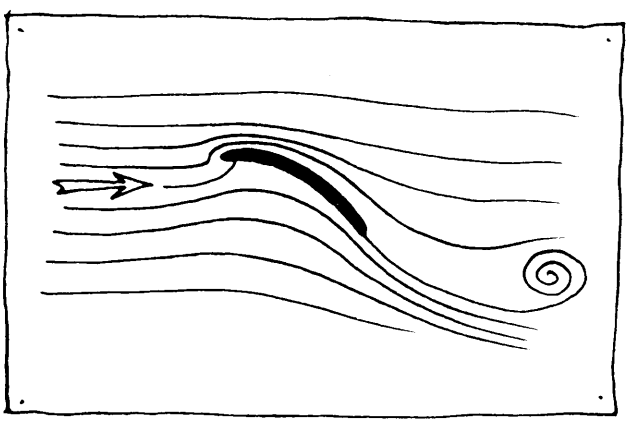
IN THESE DRAWINGS YOU CAN SEE HOW THE FLOW AROUND THE SPOON CHANGES AS IT GETS AWAY FROM LOWER SPEEDS.

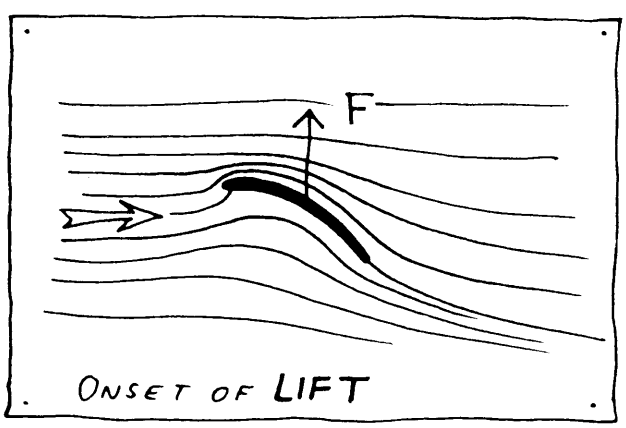
AN EDDY DETACHES ITSELF, AND THIS ESTABLISHES A SYSTEM OF EXCESS SPEED ACROSS THE BACK (TOP) AND REDUCED SPEED ROUND THE INSIDE (BOTTOM).

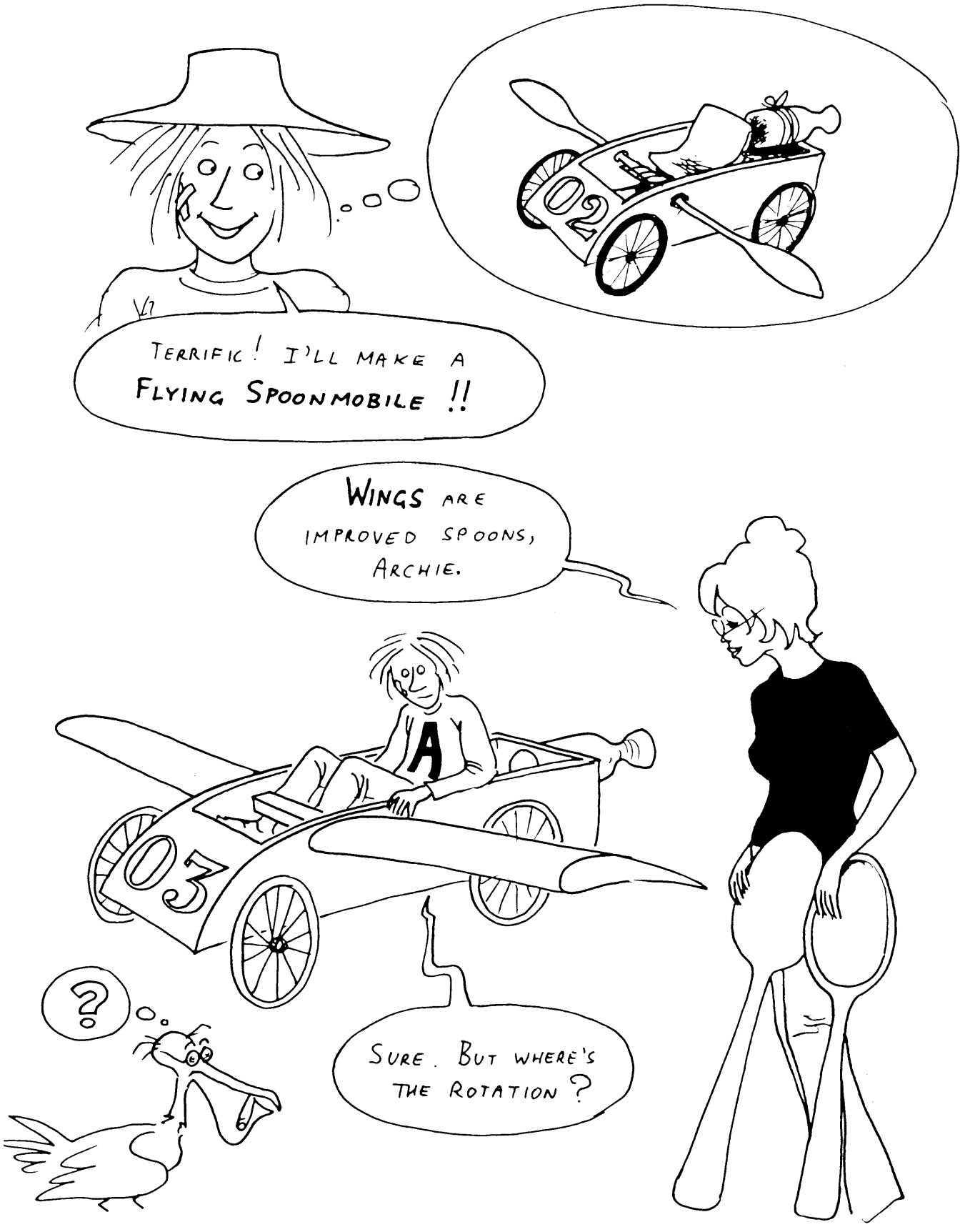


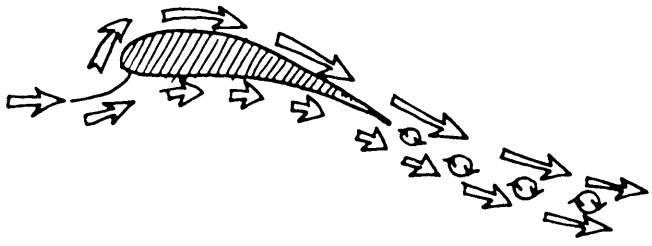






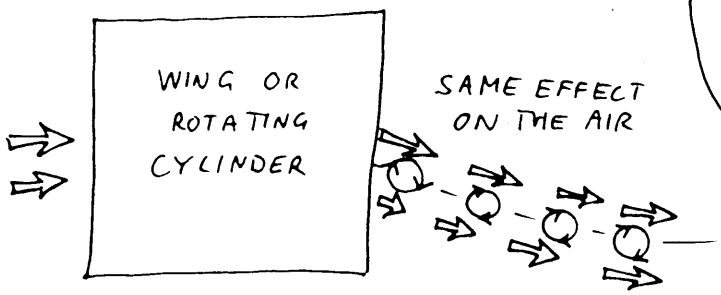


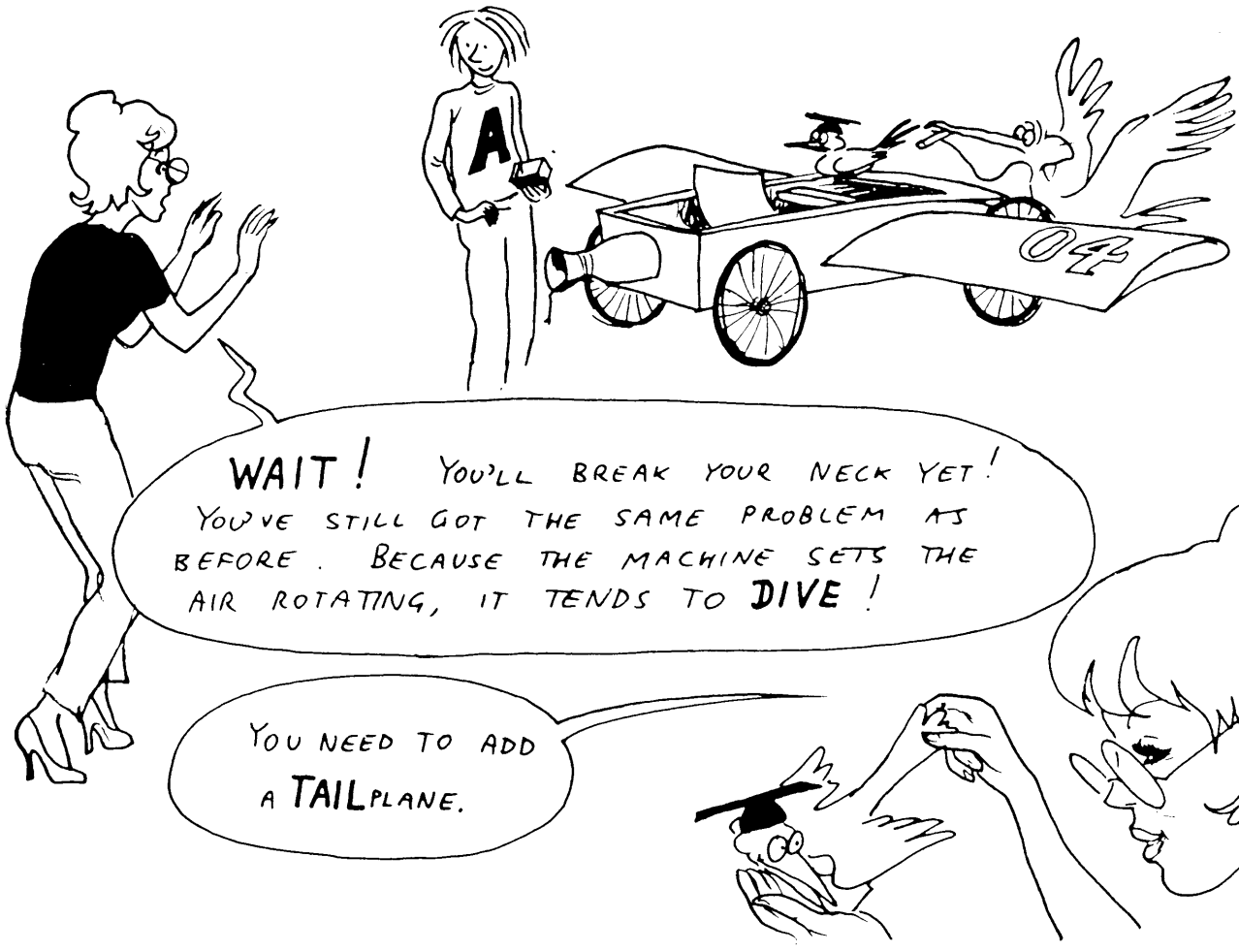

02
TERRIFIC! I'LL MAKE A FLYING SPOONMOBILE !!
WINGS ARE IMPROVED SPOONS, ARCHIE.
A
03
SURE. BUT WHERE'S THE ROTATION?
?

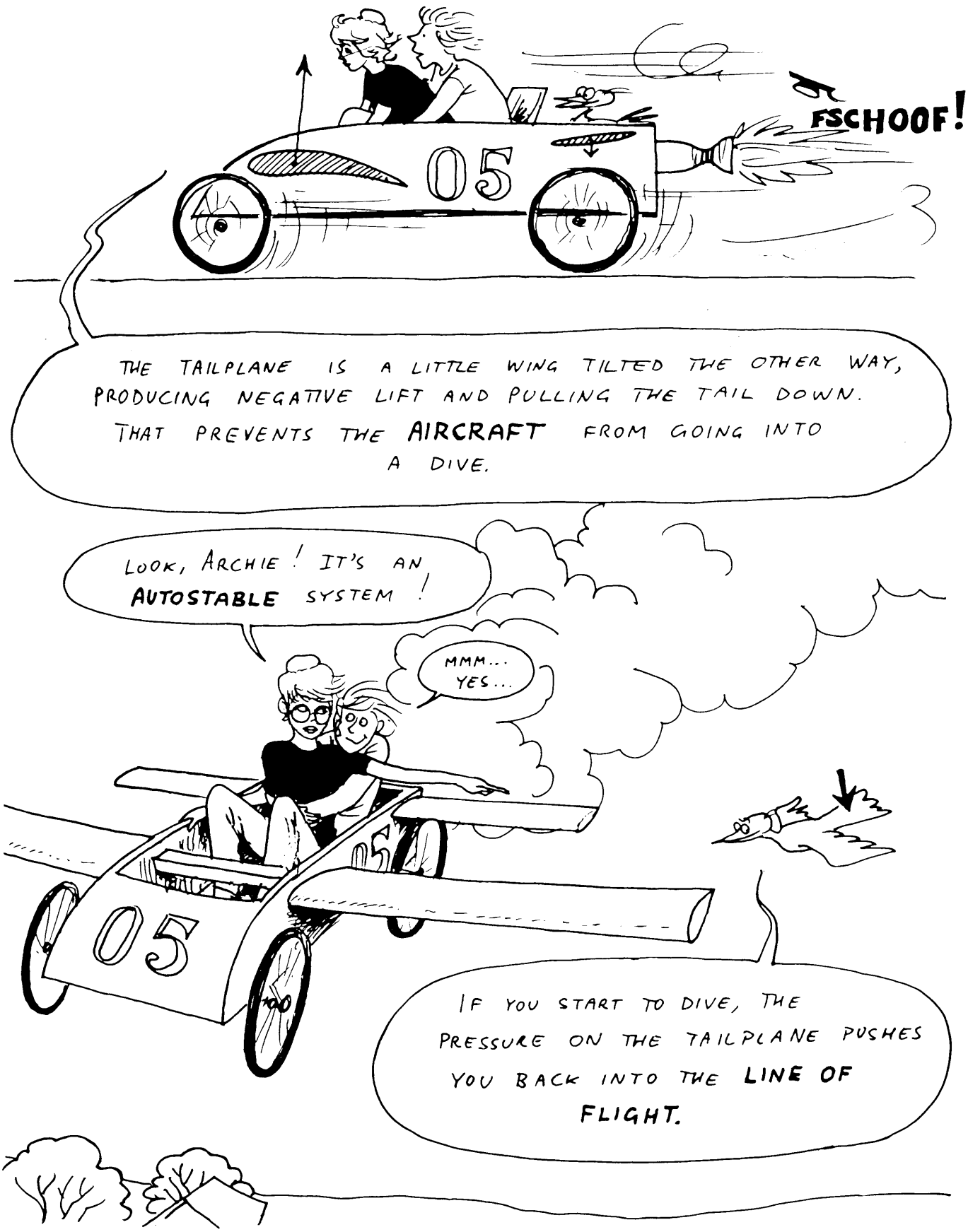


DOWNSTREAM OF THE WING YOU FIND THE SAME SYSTEM OF TINY EDDIES AS BEHIND THE ROTATING CYLINDER.

SO YOU CAN THINK OF A WING AS A **FIXED ROTOR.**





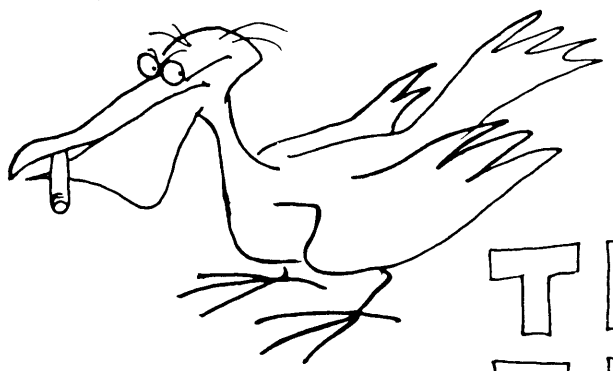

FSCHOOF!
05
THE TAILPLANE IS A LITTLE WING TILTED THE OTHER WAY, PRODUCING NEGATIVE LIFT AND PULLING THE TAIL DOWN. THAT PREVENTS THE AIRCRAFT FROM GOING INTO A DIVE.
LOOK, ARCHIE! IT'S AN AUTOSTABLE SYSTEM!
MMM... YES...
05
IF YOU START TO DIVE, THE PRESSURE ON THE TAILPLANE PUSHES YOU BACK INTO THE LINE OF FLIGHT.


THE SAME THING HAPPENS IF YOU CLIMB.
ARCHIE! YOU'RE NOT PAYING ATTENTION!
I AM, I AM! I'M HANGING ON YOUR EVERY WORD!
MY WORD SEEMS TO HAVE BECOME MISPLACED.
I REALLY DIG THIS AUTOSTABLE FEELING!

AND THAT, O BEST BELOVED, IS 'OW ARCHIE 'IGGINS GOT 'IS WINGS.

IN THE END IT WAS AS EASY AS PIE IN THE SKY.

AND 'IS SCIENTIFIC URGES CAN ONLY GROW WIV ALTITUDE...



THE END